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IFRO Report 274

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This report has been elaborated as part of a comparative project initiated by the Danish Environmental Protection Agency, the Ministry of Environment and Food. The project has the purpose to compare the ammonia regulation of livestock installations with a particular view to Natura 2000 sites and the EU Habitats Directive. The project as a whole consists of three parts analysing the situation in Denmark, Germany – with a particular focus on Schleswig-Holstein – and the Netherlands from a legal perspective, an economic perspective and a natural science perspective.

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Summary

This report is part of the analyses in the Natura and Ammonia project initiated by the Environmental Protection Agency under the Ministry of Food and Agriculture. The purpose of the overall project is to look at the regulation with respect to ammonia emissions from livestock farms near Natura 2000 sites in Germany, The Netherlands and Denmark. The analyses include the nature, legal and economic perspectives. The purpose of this report is to give a short introduction to Danish agriculture and then to analyse the additional costs involved when farms want to increase their livestock farm near Natura 2000 sites (category 1 habitats) or other nature sites outside Natura 2000 (category 2 and 3 habitats) in Denmark.

The overview of the current livestock in Denmark shows that most livestock farms are located in the western part, whereas the Natura 2000 sites are located across the whole country. The majority of livestock is located more than 1,000 metres away from category 1 or 2 nature, whereas most livestock is situated less than 1,000 metres from either category 1, 2 or 3 nature. Farms near Natura2000 (< 1,000 m) have an average size of 20 animal units (AU) (10-15 per cent) and are smaller than farms more than 1,000 metres away from Natura 2000 sites (category 1-2).

The overview of the current housing systems show that farms are moving towards lower ammonia emission solutions although only 22 per cent of new applications actually include new housing technology. It is assumed that the local authorities will give permits to 320 applications every year of which 30-40 applications are related to expanding livestock farms near Natura 2000 sites (category 1) as this is assumed to require the use of new technology in the buildings. This indicates that probably around 10 per cent of all livestock are involved in applications every year.

The regulatory setup in Denmark is rather complex, but in relation to the expansion of livestock, the general requirements regarding ammonia emissions are linked to the Best Available Technology requirements (BAT), which all livestock farms have to fulfil (MST, 2016). Furthermore, for livestock farms, who want to expand near category 1-3 nature, further restrictions are in place, which will limit the allowed ammonia emissions from the farm after expansion. The emission requirements related to expansions near category 1 and 2 nature are based on the total emission from the farm (total deposition). In case the farm is located near category 3 nature, the focus is on the additional emissions from the expansion. The allowed deposition for farms near category 1 nature is linked to standard national values, whereas the requirements near category 3 are based on a local assessment. In some cases, the allowed ammonia emission after expansion can be lower than before the expansion.

The analysis is based on the livestock regulation, which was in place until 1st of August 2017 (Folketinget, 2017). The calculations are carried out for three case farms (finishers, dairy cows and broilers) and the expansion analysed is an increase of the livestock production by 100 per cent. After the expansion, the finisher farm produces 14,430 finishers; the dairy farm has 240

cows and the broiler operation have a production of 600,000 chickens a year. The case farms are located 400 and 2,000 metres away from ammonia sensitive nature, respectively.

The ammonia emission requirements for the case farms are calculated by the Environmental Protection Agency using the standard application tool (husdyrgodkendelse.dk). The report then describes a range of technologies available to the farmer in order to meet the emission requirements. The technologies include air scrubbers, cooling, as well as acidification, which is commonly used in Denmark. It can be a challenge to find the technology or combination of technologies, which gives the right effect as not all technologies work well together and thus do not achieve a full additional effect.

The results indicate that farms intending to expand their farm near (within 400 metres of) category 1 nature, where there are no livestock neighbours, and near category 2 and 3 nature sites will typically have costs in the range of 0-90,000 DKK/year. The cost will often not be too high to prevent the expansion intended based on the cost per unit compared to the intended limit per unit set in the regulation. The analysis indicates that new technology in the stables would be required in most cases, but it could be that some farms are able to fulfil the requirements without this as they use changes in feeding, cover of slurry storage etc.

For investments near (400 metres) category 1 with one or more livestock neighbours, the costs are higher and the technology requirement more complex. The costs are from 120-280,000 DKK/year and so the costs will in some cases be too high for the farmer and so the investment will probably be abandoned. Also, the technology options will sometimes have to be combined and in some cases the technology available cannot give the required emission reductions. For farms 2,000 metres away from nature sites (category 1), the analysis shows that there are no additional costs and so no additional technology has to be implemented.

A rough estimate of the total costs has been calculated. The interval of 3-9 million DKK/year for livestock farms actually expanding near nature sites (category 1-3) is very uncertain and is only provided to give a cost level for applications from one year. Compared to the total costs on farms, this value is limited, but the costs can be a large burden for some farms. The analyses have not looked at the costs in cases where existing farms decide not to increase their production, or the costs for existing farms, which are given new emission limits when they carry out larger reinvestments (limit increase in production) (re-assessment).

In order to give a better estimate of the costs, a better overview of the current application needs to be provided so that the requirements can be better linked to the different nature categories. Furthermore, the analysis could include more case farms and sizes based on the actual applications made.

Sammendrag

Denne rapport er en del af analyserne i Natura- og Ammoniakprojektet, der er igangsat af Miljøstyrelsen under Ministeriet for Fødevarer og Landbrug. Formålet med det overordnede projekt er at se på reguleringen af ammoniakemissioner fra husdyrbrug nær Natur 2000-steder i Tyskland, Holland og Danmark. Analyserne omfatter natur-, juridiske og økonomiske perspektiver. Formålet med denne rapport er at give en kort introduktion til dansk landbrug og derefter analysere de ekstra omkostninger, der følger af, at bedrifter ønsker at udvide deres husdyrbrug nær Natura 2000-steder (kategori 1-habitater) eller andre naturområder uden for Natura 2000 (kategori 2 og 3 levesteder) i Danmark.

Oversigten over nuværende husdyr i Danmark viser, at de fleste husdyrbrug ligger i den vestlige del, mens Natura 2000-lokaliteterne er placeret over hele landet. Størstedelen af alle husdyr er placeret på bedrifter, der ligger mere end 1.000 meter væk fra kategori 1- eller 2-natur, men mange er i nærheden af anden natur udenfor Natura 2000 (kategori 3-natur). Gårde i nærheden af Natura 2000 har en gennemsnitlig størrelse, der er 20 dyreenheder (10-15 procent) mindre end gårde, der ligger mere end 1.000 meter væk fra Natura 2000-arealer.

Oversigten over omfanget af ansøgninger om husdyrgodkendelser viser, at kun 22 procent af ansøgninger indeholder ny miljøteknologi. Det antages, at de lokale myndigheder vil give tilladelse til 320 ansøgninger hvert år, hvoraf 30-40 ansøgninger vedrører ekspanderende husdyrbrug nær Natura 2000-steder (kategori 1), da det antages at kræve implementering af ny miljøteknologi i bygningerne. Opgørelsen indikerer, at kun cirka 10 procent af alle ansøgninger er koblet til ansøgning om udvidelse af husdyrproduktionen nær Natura 2000.

Husdyrreguleringen i forhold til udvidelsen af husdyr er ret kompleks, men som udgangspunkt gælder de generelle krav til ammoniakemissioner, som gør, at der for alle bedrifter er et krav om at anvende den bedste tilgængelige teknologi (BAT). Derudover gælder yderligere krav for husdyrbrug, der ønsker at udvide nær kategori 1- til 3-natur. Emissionskravene vedrørende udvidelser nær kategori 1- og 2-natur er baseret på den samlede emission fra bedriften (totaldeposition), og for kategori 1 også hvor mange husdyrbedrifter der er som naboer. Hvis gården ligger i nærheden af kategori 3-natur, er fokus på merdepositionen. Den tilladte deponering til gårde i nærheden af kategori 1-natur er knyttet til standard nationale værdier, mens kravene nær kategori 3 er baseret på en lokal vurdering. Den tilladte ammoniakemission efter ekspansion kan i nogle tilfælde være lavere end før ekspansionen.

Analysen er baseret på den husdyrreguleringen, der var gældende indtil 1. august 2017. Beregningerne udføres for tre bedriftstyper (slagtesvin, malkekøer og slagtekyllinger), og den analyserede udvidelse udgør 100 procent i forhold til udgangspunktet. Efter udvidelsen producerer slagtesvineproducenten 14.430 slagtesvin, mælkeproducenten har 240 køer, og der produceres 600.000 slagtekyllinger. Casebedrifterne ligger henholdsvis 400 og 2.000 meter væk fra ammoniakfølsom natur.

Kravene til ammoniakudledningen er beregnet af Miljøstyrelsen ved hjælp af standard ansøgningsværktøjet (husdyrgodkendelse.dk). Rapporten beskriver derefter en række teknologier, der er tilgængelige, for at landmændende kan opfylde emissionskravene. Teknologierne omfatter luftrenser, gyllekøling samt forsuring, som almindeligvis anvendes i Danmark. Det kan i nogle tilfælde være en udfordring at finde teknologier eller kombinationer af teknologier, der giver den rigtige effekt, da ikke alle teknologier fungerer godt sammen og dermed ikke opnår en fuld yderligere effekt. I nogle tilfælde kan det ønskede reduktionskrav ikke nås.

Resultaterne viser, at gårde, der har til hensigt at udvide deres gård i nærheden af (400 meter) kategori 1-natur, hvor der ikke er nogen husdyrbedrifter i nærheden, og bedrifter, der ligger nær kategori 2- og 3-naturområder, typisk vil have relativt lave omkostninger i størrelsesordenen 0-90.000 kroner per år. Omkostningerne vil typisk ikke være så høje, at udvidelsen ikke gennemføres. Analysen indikerer, at der i de fleste tilfælde vil være behov for ny teknologi i stalde, men det kan være, at nogle gårde er i stand til at opfylde kravene uden dette, da de bruger ændringer i fodring, dækning af gylleoplagring med videre.

For investeringer nær (400 meter) kategori 1, med et eller flere husdyrbrug som naboer, er omkostningerne højere, og teknologikravet er mere komplekst. Omkostningerne er fra 120.000 til 280.000 kroner om året, og omkostningerne vil i nogle tilfælde være for høje for landbrugeren, så investeringen vil sandsynligvis blive opgivet. Teknologierne skal nogle gange kombineres, men i nogle tilfælde kan de tilgængelige teknologier ikke give de nødvendige emissionsreduktioner. For gårde 2.000 meter væk fra naturområder (kategori 1) viser analysen, at der ikke er ekstra omkostninger, da BAT-kravet er tilstrækkeligt, hvorfor der ikke er behov for at implementere yderligere teknologi.

Et groft estimat af de samlede omkostninger er blevet beregnet. Intervallet er på 3-9 millioner kroner om året, for alle husdyravlere der rent faktisk udvider nær naturområder (kategori 1-3). Estimatet er meget usikkert, og det omfatter altså kun et omkostningsniveau for ansøgninger fra et år. Sammenlignet med de samlede produktionsomkostninger i landbruget er denne værdi begrænset, men omkostningerne kan være en stor byrde for nogle bedrifter. Analyserne har ikke undersøgt omkostningerne og værditab for eksisterende bedrifter der ikke kan øge deres produktion. Omkostningerne for eksisterende bedrifter, der får nye emissionsgrænser, indgår heller ikke i analysen.

For at give et bedre skøn over omkostningerne kræves et bedre overblik over de nuværende ansøgninger, så kravene bedre kan knyttes til de forskellige naturkategorier. Kravene kan variere specielt med hensyn til kategori 3-natur. Desuden kunne analysen udvides til at omfatte flere bedriftstyper og -størrelser med udgangspunkt i de faktiske ansøgninger.

1. Introduction

This report is part of the analyses in the Natura and Ammonia project initiated by the Danish Environmental Protection Agency (called Miljøstyrelsen, from now on abbreviated to MST) under the Ministry of Food and Agriculture. The purpose of the overall project is to compare the regulation of livestock farming near Natura 2000 sites in Germany, The Netherlands and Denmark.

The purpose of this report is to describe the additional costs involved when farms want to increase their farm near Natura 2000 sites or other nature sites (category 2 and 3) in Denmark. Category 1 habitats are habitats, which are considered ammonia sensitive, and which are situated within Natura 2000 sites. Category 2 habitats are selected habitats located outside Natura 2000, and category 3 habitats are other habitat, for example protected by the Nature Protection Act (§ 3) (see Figure 3).

The report starts with a brief description of Danish agriculture and the designated Natura 2000 areas in Denmark. A more detailed description of the Natura 2000 selection and the regulation implemented today can be found in the Danish sub-reports regarding the nature impacts and the legal aspects (Fredshavn et al., 2017; Anker & Baaner, 2017).

The report then goes on to describe the technologies the farmers can choose as well as their effects and costs. In the analysis, economy of scale in relation to technical solutions is also described. In cases where several technologies are used in combination, the overall efficiency is discussed.

The baseline for the analysis is the general requirement for ammonia emissions and use of BAT technology required by all Danish livestock farms who want to expand their business. This requirement has been important in the reduction of the ammonia emissions over the past years. The Danish emissions have been reduced by 43 per cent from 1990 to 2015 (from 125 kt NH_3 to 71kt NH_3) (Mikkelsen & Albrektsen, 2017). A further reduction of 7 kt NH_3 is required to reach the 2020 and 2030 target of 64 kt NH_3, which is 24 per cent under the 2005 emission level (European Commission, 2015).

The calculations are carried out as financial economic analyses, looking at the additional yearly cost for the farmer of using different technologies compared to the baseline. The cost estimation is based on the lifespan of the technology, and an interest of 4 per cent has been applied. The aim is not to describe the overall farm profit for the farms.

Based on the selection of three case farms, it is analysed what the additional costs of implementing the required technology would be when the farm is located relatively near nature sites (400 metres from category 1, 2 and 3 nature) and further away (2,000 metres from nature sites). Category 1 nature is Natura 2000 sites, whereas category 2 and 3 nature sites are located outside the Natura 2000 sites. The basic assumption is that the case farms are planning an expansion of 100 per cent of their current production size. The calculation for category 2 and 3 was limited to finishers to show the approached used.

Based on the number of farms that are given an ammonia reduction requirement related to the nature category 1-3 when they expand the farm, the aim is to give a very rough estimate of the additional national costs for the farms in relation to the protecting of the category 1-3 nature sites focusing only on farms increasing their size. Professor Mette Termansen, IFRO, has carried out the internal review. For a comparison with conditions in Germany and the Netherlands, we refer you to Jacobsen and Ståhl (2018) and Jacobsen et al. (2018).

2. Danish Agricultural Production and Use of the Agricultural Area

This section describes the agricultural production including both the arable and the livestock sector, and the most typical farm types are presented. The overall production figures are shown as well as the share of the production, which is exported. The location of the agricultural production in relation to the Natura 2000 areas is also described, including an overview of the key issues related to the possibility of increasing the livestock production at different locations. This section finishes with a description of the case farms, which will be analysed in more detail in the forthcoming sections.

2.1. Agricultural Production

The number of farms, the use of the total agricultural area, and the total livestock production is shown in Table 1. The total number of farms has fallen over the years and is now around 36,000 farms. Almost 10,000 farms are classified as full time farms today (workload more than 1,665 hours/year).

Table 1. Data for the Danish Agricultural Production

Description	2010	2016	2016 AU* (1,000)
Number of farms (full and part time)	42,099	35,674	
Total agricultural area (million ha)	2.65	2.63	
- Grassland	0.20	0.23	
- Green feed crops	0.56	0.51	
- Arable crops	1.47	1.47	
- Horticulture	0.02	0.02	
Number of animals (x 1,000)			
Cattle total	1,571	1,568	--
- Dairy cows	568	572	762
- Young dairy cattle (heifers)	329	321	153
Sheep	160	147	--
Total pigs	29,908	27,156	--
- Finishers (animals in stock) - Finishers (slaughtered)	3,509 20,244	2,969 17,742	 455
- Sows (stock)	1,117	999	227
Chickens total	18,084	17,898	--
- Laying hens	3,900	4,644	27
- Broilers (stock) - Broilers (slaughtered)	12,836	11,745 101,600	- 33
Others (calves, piglets, mink etc.)			474
Total livestock			2,131

* AU (DE in Danish) = livestock units = 0.75 dairy cow (large) = 39 finishers (32-107 kg) = 208 piglets (7.2-32 kg) = 4.4 sows (with piglets up to 7.2 kg) = 3,020 broilers (35 days) = 170 hens = 100 kg N from storage.
AU is not the same as LSU used by Eurostat, where 1 LSU = 1 dairy cow = 3.3 pigs = 0.5 sows = 0.007 boilers (Eurostat, 2013). According to the EU, the total amount of livestock in Denmark in 2013 was 4.1 million LSU (Eurostat, 2017). That gives 1.5 LSU/ha compared to EU average of 0.7 LSU/ha (Farm EU con consensus data (130 mio. LSU / 175 mio. ha)).
Sources: Eurostat (2013; 2017); Statistics Denmark (2017). The calculation of animal units does not cover all types of animals in detail. The total amount of livestock is 2.1 million AU in 2014 (Conterra, 2015) and in 2016 (Jesper Bak, Aarhus University, personal communication, 2017).

2.1.1. Arable farming

The total Danish area is 4.3 million ha of which 2.63 million ha were cropped in 2016. In total, around 60 per cent of the entire area is cropped, which is among the highest in Europe where the average is around 40 per cent. Most of the cropped area in Denmark is in rotation and the share with permanent grass is limited (8 per cent). The main crops in Denmark are wheat and barley, covering more than half of the agricultural area. Fodder crops, mainly grass and maize for silage, amount to around 750,000 hectares, but Denmark is also an important producer of sales crops such as rape seed, sugar beets and grass seeds of various types. Vegetables and potatoes cover 60,000 hectares. Denmark is traditionally divided into two main parts namely Jutland and the Islands (mainly Zealand and Funen). The agricultural area of Jutland is 1.8 million ha (70 per cent), whereas Funen and Zealand together with the other Islands cover 30 per cent. The dominant soil type in the western part of Jutland is a sandy soil, whereas the soils in the eastern part of Jutland, Funen and Zealand are predominantly clay soils.

2.1.2. Livestock production

Danish farmers produce around 18-20 million slaughter hogs or finishers per year. The number has been going down in recent years as the export of live piglets to Germany has increased to more than 13 million. There are around 1 million sows and the number of piglets produced per sow is now more than 31 (SEGES, 2017c).

The milk production amounts to around 5,350 million kg in 2016 from around 570,000 dairy cows (Statistics Denmark, 2017). The number of cows in 2016 was up by 2 per cent compared to 2014 (Statistics Denmark, 2017). The milk production increased by 7 per cent from 2012 to 2015 but dropped by less than 1 per cent from 2015 to 2016. Besides the production of milk and pork, Denmark produces poultry and mink. Generally, two-thirds of the Danish agricultural production is exported.

The livestock density is the highest in Jutland and especially in selected parts of the region (see Figure 2). The most intensive regions are pig farming regions in the northwest of Jutland and the Southeast of Jutland. The dairy farms are mainly located on sandy soils and especially in the south-western part of Jutland. Based on the total Danish livestock units (1 AU = 100 kg N from storage), the total livestock units are around 2.1 million AU in both 2009 and 2017 (Statistics Denmark, 2010; Jesper Bak, Aarhus University, personal communication, 2017). The average livestock density in Denmark is 0.8 AU/ha. Based on the Eurostat livestock units (LSU), the average Danish livestock intensity is 1.5 LSU/ha, which is larger than the EU average of 0.8 LSU/ha for EU-28, but lower than the level in the Netherlands (3.7 LSU/ha) (Eurostat, 2017).

2.1.3. Farm types

The number of farms in Table 2 are all full-time farms, which means that the annual workload on the farm is more than 1,665 hours/year. The farms are divided according to which production makes up the main economic activity based on the standard economic gross margin (SGM).

Table 2. Number of farms per farm type and the average size in agriculture areas and number of animals per farm in Denmark in 2015*

Farm type	Number of farms [1) a)]	Cultivated area (ha/farm) [b)]	Net profits (1000 € /farm)[3) b)]	Dairy cows (number/ farm)[b)]	Finishers (produced per year/ farm)[b)]	Sows (number /farm) [b)]	Laying hens (number/ farm) [b)]	Broilers (number / farm) [b)]
Arable farms	2,351	259						
Horticulture farms**	723	40						
Other cattle than dairy cattle	442	84	-5.2	262				
Dairy farms	2,860	154	-74.5	179				
Pigs	2,520	166	-111.3					
- Finishers	1,215	158	-53.0		9,870			
- Sows and piglet production	855	120	-192.8			842		
- Sows, integrated production	451	272	-113.6			435		
Poultry, total [b)]	276	148						
- Egg laying hens [b)]	103		107.4				33,400	
- Broilers [b)]	173		1.1					676,000
Other	2,327							
All full-time farms (including organic farms)	10,776[2)]	167						

[1)] Full-time conventional farms
[2)] Consists of conventional farms (10,163) and organic farms (613), but not horticultural farms (723)
[3)] Net profit is the gross margin minus fixed costs and calculated salary to the owner.
Sources:
a) Statistics Denmark (2016b)
b) Statistics Denmark (2016a)

As shown in Table 2, the number of full-time farms today is around 10,000 compared to the total number of farms, which is around 35,000 farms. The full-time arable farms are larger than the average farm shown at the bottom of Table 2. The full-time farms own about 1.8 million ha (68 per cent) and produce the large majority of total livestock. The farms that focus on milk production have on average 179 cows, and the pig farms with only sows have around 840 sows per farm. There has been a large increase in herd sizes over the last years.

In Table 2, the net profits are also included. Net profit is the total earning minus variable and fixed costs including a calculated payment to the owner of the farm. The table shows that the return after a calculated payment to the owner is negative for most farms indicating the low income level, which has been the case for many types of farms in 2015. The calculated payment to the owner is based on the alternative payment in other sectors (192 DKK/hour or 25.6 euros/hour) times the number of hours spent on the farm according to the owner. Seen over a five year average, only crop production has had a positive return based on farm profit after calculated payment to the owner based on the time spent (Statistics Denmark, 2017).

2.1.4. Export value

The total value is shown in Table 3. The dairy products constitute around 40 per cent of the value and the pig related products around 56 per cent of the total value.

Table 3. Export value of Danish Agriculture in 2016 (selected sectors)

Product	Value in million euros	Share (%)	Share of total agricultural export (%)
Pig meat and their meat products	2,690	43	
Cheese	1,303	21	
Live pigs	844	13	
Other dairy products	768	12	
Cattle meat and their meat products	333	5	
Poultry meat and their meat products	305	5	
Eggs and egg products	62	10	
Total for selected products	6,305	100	42
Other agricultural exports (Processed products, food preparations, beverages and non-edible)	8,724		58
Total agricultural exports	15,029		100

Note: The focus is on dairy, pig and poultry products. Exchange rate used: 7.46 DKK/EURO.
Category: SITC5R4Y: Imports and exports (REV 4- SITC) and with selected groups.
Source: European Commission (2017); Statistics Denmark (2017b).

The total Danish exports are around 147,000 million euros, of which the total agricultural export accounts for approximately 15,000 million euros (10 per cent). The exports in Table 3 are the export of the main primary products, whereas the total agricultural export includes export from the whole agribusiness sector (European Commission, 2017).

2.1.5. Housing systems

The current farming systems are described in Table 4 and these findings are used to find the case production systems analysed later so that the case farms selected have a production system, which represents a large share of the production in each category. Table 4 includes a description used in a previous analysis related to ammonia emission and forecasts for future ammonia emission from Denmark. For the column related to the forecast of ammonia emission in 2020, the production has been linked to technology implemented, such as acidification (see e.g. JH Staldservice, 2017) or how the manure is used afterwards (biogas). For these technology options or installations, a standard housing system has been assumed in the calculation of the expected ammonia emission (see note below the table) and so for dairy cows, 85 per cent will be in cubicle housing, in effect, in 2020. Biogas is included even though it has no NH_3 impact as the same projection is used for GHG forecasts for the agricultural sector in Denmark.

Table 4. The production and housing systems used in Denmark in 2004, 2012 and forecast 2020 for the most common animal categories (share of livestock in each system (per cent))

Livestock category and production systems	2004[1)]	2012/13[2)]	2020[3)]
Dairy cows (large breed)			
- Tie-stalls	24	7	5
- Cubicle housing	65	86	52
- Deep bedding	11	7	3
- Biogas (*	--	--	33
- Acidification in the buildings	--	--	7
Total	100	100	100
Pigs finishers			
- 100 % slatted	33	0	0
- Partly slatted/partly solid (25-75)	38	37	22
- Drained and slatted (33/67)	20	60	25
- Others (including deep bedding)	9	3	1
- Biogas (*	--	--	41
- Acidification in the buildings (*	--	--	2
- Slurry cooling (*	--	--	5
- Air scrubbers (*	--	--	3
Total	100	100	100
Sows			
- 100 % slatted	12	8	2
- Partly slatted	51	80	63
- Solid floor	5	0	0
- Deep bedding	30	11	7
- Others (including sows outside)	2	0	1
- Air cleaning (*	--	--	7
- Acidification (*	--	--	1
- Slurry cooling (*	--	--	20
Total	100	100	100
Hens			
- Free range	7		6
- Organic	16		24
- Free range (indoor) (floor housing)	20		24
- Cage hens	57		0
- Air cleaning (*	--		25
- HPR (broiler breeder)	--		21
Total	100		100
Broilers			
regular housing (39 days)	100		
- regular housing (32 days)	--	17	16
- regular housing (35 days)	--	79	25
- regular housing (40 days)	--	3	4
- Organic and free range (skrabekyllinger)	--	1	2
- Heat exchange	--	--	50
Total	100	100	100

In the calculations of the emissions in Mikkelsen & Albrektsen (2017) a reference stable has been assigned together with the technology described here (biogas, air cleaning etc.). These are:

- Dairy cows: cubicle housing with slats
- Finishers: partly slatted (25-49 per cent solid floor)
- Sows: farrowing partly slatted floor
- Hens: egg laying hens (free-range indoor)

Broilers: 35 days regular housing chickens (35 days).

Sources: 1) Aaes et al. (2009) (Appendix 1); 2) Kai & Adamsen, 2017 (+ own calculations); 3) Mikkelsen & Albrektsen (2017)

As seen in Table 4, the most common housing system for dairy cows is now cubicles (with over 80 per cent) and this is not expected to change in the coming years. For finishers, the drained and slatted floor is the most common, but it is expected that the partly slatted/partly solid floor will increase in share. For sows, the partly slatted floor is the most common. For hens and broilers, the most common types are free-range/organic and 35 days regular housing respectively. Heat exchangers are expected to be used on half the broiler farms.

2.2. The Location of Agricultural Production in Relation to Natura 2000 Sites

Natura 2000 sites are nature protection areas in the EU. The purpose is to protect different habitat types and wild animals as well as rare plants. A total of 252 Natura 2000 sites have been designated in Denmark. Together, these sites cover an area corresponding to the size of the Danish island of Funen and its surrounding islands (8 per cent). The basis for Natura 2000 is the EU Birds Directive and Habitats Directive and so the habitat and bird protection sites have been designated in order to protect specific species and habitats. As shown in Figure 1, which includes Natura 2000 areas at sea and on land, the areas are scattered over the whole country. The total Natura 2000 area on land amounts to around 260,000 ha. It has been calculated that the Natura 2000 sites on land include around 120,000 ha ammonia sensitive nature. The Environmental Protection Agency has found that the total agricultural area within Natura 2000 sites is 72-85,000 ha depending on whether only intensive or also extensive farm areas are included (Andersen, 2017).

The Environmental Protection Agency have suggested changes with respect to the Natura 2000 areas in Denmark in 2017 so that around 21,000 ha of agricultural area (25 per cent of the agricultural area in Natura 2000) would be taken out of the Natura 2000 areas and that around 1,100 ha of agricultural area is expected to be included. The area included in the future Natura 2000 map is located some distance from current livestock operations and so it seldom will have an impact on the present livestock operations. The purpose is to take agricultural areas with relative low nature value out of the Natura 2000 mapping and include more nature (4,000 ha nature area is included). The corrections are also linked to the transformation from hand-drawn maps to digitised maps, why many of the changes are very small (Hansen et al., 2017). We define agricultural areas as areas that are eligible for basic land payment (EU area payment).

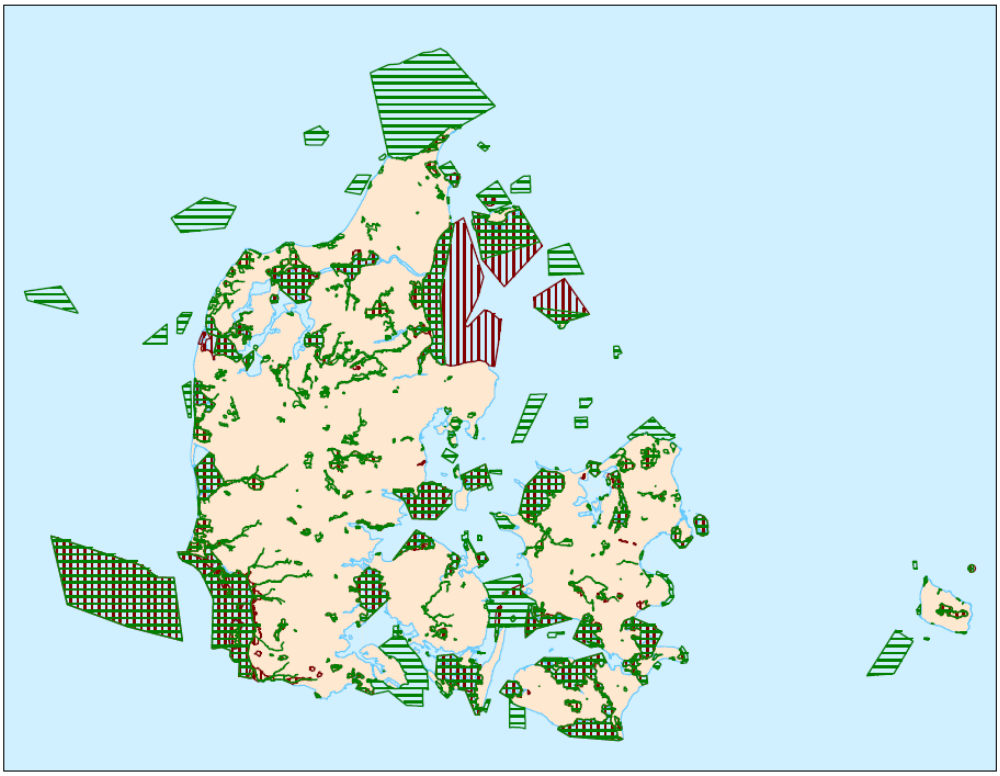

Figure 1. Location of Natura 2000 sites in Denmark
Source: The Environmental Protection Agency (pers. comm.)

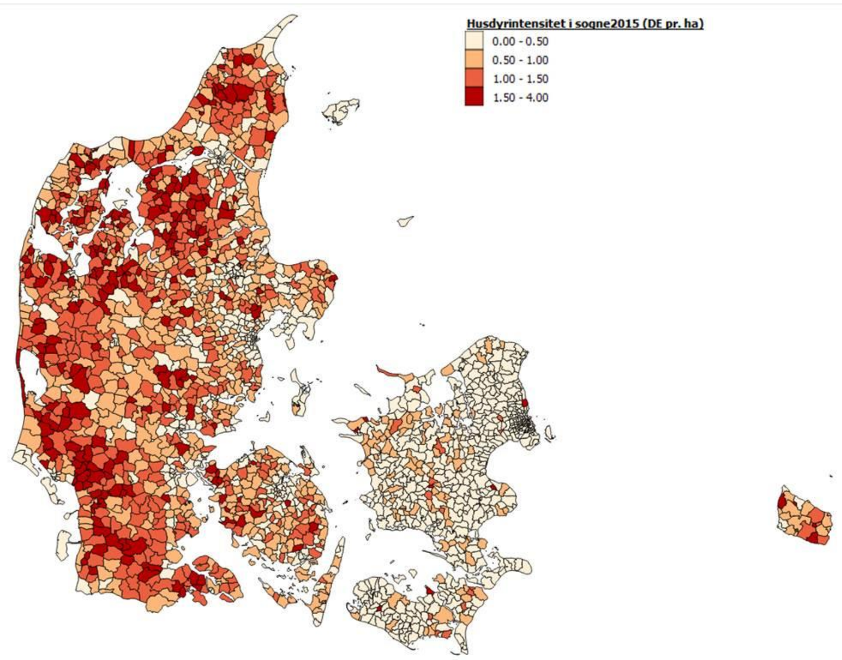

Figure 2. Livestock intensity per sub-municipality in 2015
Source: Jens Erik Ørum, University of Copenhagen, personal communication

The distance from livestock production to ammonia sensitive nature in Natura 2000 sites is shown in Table 5. It also shows the distance to category 2 and 3, which is nature outside Natura 2000 sites. The analysis is based on a GIS analysis performed by Aarhus University (Jesper Bak, personal communication, 2017). As shown, a limited share of the livestock production is closer than 500 metres to category 1 and 2 nature in the partial analysis (4, 1 and 6 per cent, respectively) looking only at one type of nature at the time. For category 3, around 48 per cent of the livestock production is within 500 metres and so a local assessment has to be made in case of applications regarding an expansion.

Table 5. Share of total livestock production (AU) near category 1, 2 and 3 nature independently or together (per cent) (n= 12,876 farms and 2.1 million AU)

Distance (m)	Category 1 Nature (separate)[1)]	Category 1 Forest (separate)[1)]	Category 2 Nature (separate) [1)]	Category 3 Nature (separate) [1) 2)]	Share of AU further away than a given distance (cat. 1 and cat. 2 nature combined)*	Share of AU further away than a given distance (cat. 1, 2 and 3 nature combined)*
< 200	1 %	0 %	2 %	13 %		
200-500	3 %	1 %	4 %	35 %	97 %	83 %
500-750	3 %	1 %	5 %	22 %	88 %	
750-1000	3 %	1 %	6 %	14 %		
1000-1500	7 %	3 %	13 %	11 %	73 %	14 %
1500-2000	7 %	3 %	12 %	3 %		
>2000	76 %	90 %	59 %	2 %	44 %	
	100 %	100 %	100 %	100 %		
Average (m)	4.584		2.836	617		

[1)] Categories 1 and 2 have requirements regarding maximum total deposition levels, whereas category 3 is regulated on the additional deposition valued by the municipality (see later).
[2)] Forest is not included in the calculation.
Note: * The distance used in the calculation is based on the lower value of the interval.
For a more detailed description on the nature categories, see section 3.1.
Source: Jesper Bak, DCE, Aarhus University, personal communication, 2017) and own calculations.

The Environmental Protection Agency have not collected data regarding the category 3 requirements issued by the municipalities until 2017, and so it is uncertain to which extent proximity to category 3 nature requires further reduction requirements. Later analyses indicate that in many cases, municipalities set a limit of additional deposition of 1 kg N/ha. In the analysis, the base deposition is also included. It is assumed, based on talks with the Environmental Protection Agency, that less than half of farms near (under 1,000 metres) category 3 will be given further emission reduction requirements.

As shown in Table 5, most livestock farms are more than 1,000 metres away even when category 1 and 2 requirements are combined (73 per cent). However, when category 3 nature is included, only 14 per cent of the livestock production is more than 1,000 meters from all nature categories

(1-3). Since many farms will not experience category 3 nature requirements, the number of farms with emission restrictions will be lower.

In a similar analysis, DCE has found that 8 per cent of all the livestock farms are situated near category 1 nature (size and distance together) (Levin & Nygaard, 2017). The number of large full-time farms (> 150 AU) near category 1 is around 1,200 farms. The share of livestock farms near category 1, 2 or 3 is, as expected, somewhat higher in the analysis by Levin and Nygaard (2017). The analysis shows that 11 per cent of the applications were close to category 1 nature, which is not too far from the assumptions made in this report. The distance included in the analysis varies with farm size and type.

Livestock farms located closer than 1,000 metres to category 1 and 2 are found to be 20 AU (10-14 per cent) smaller than the average for farms further than 1,000 meter away (based on Jesper Bak, Aarhus University, personal communication, 2017). There is no clear difference with respect to size of livestock farms in relation to category 3 nature. The analysis shows that mink farms are located a little bit closer to Natura 2000 sites than the average livestock farm, as 6 per cent of all mink farms are within 500 metres as opposed to 4 per cent of all livestock (as seen in Table 5).

2.3. Selected Case Farms

As seen above, the key livestock productions are pigs (piglets and finishers), dairy cows, broilers, and hens. Mink also constitute a relative large value in the Danish farming sector, but not in terms of number of farms or animals.

The case farms included in the analysis are finishers, dairy cows, and broilers to reflect the different livestock systems. Furthermore, it has been decided to have a case farm near Natura 2000 (distance of 400 metres was chosen) and a case farm further away from Natura 2000 (distance of 2,000 metres was chosen) for each production. This is to describe the difference in ammonia emission requirements for farms close to and further away from Natura 2000 sites (see Table 5). The distance is from the farm to ammonia sensitive areas within Natura 2000 sites. For each case farm, the requirements will be linked to the different categories of nature (category 1, 2 or 3) as well as the number of neighbouring livestock farms (see next chapter). The category 2 and 3 sites are located outside Natura 2000.

The size of the expansion was set at 100 per cent of the current production as this is a typical increase in production also in a Danish context, although in practice there is a large variation in the increase in production size. The Environmental Protection Agency do not keep records on the typical increase in livestock production and the permits given by the local authorities. All requirements regarding applications are based on analyses carried out in the application system (husdyrgodkendelser.dk) (MST, 2017c) and so they can be found electronically.

Table 6. Livestock production on case farms before and after expansion

	Before expansion	After expansion
Finishers	Annual production of 7,215 finishers of 32-107 kg. 33 % drained floor and 66 % slatted floor. Slurry tanks with a required cover.	Annual production of 14,430 finishers of 32-107 kg. New building has to be decided.
Dairy cows	120 dairy cows. Cubicles with slatted flooring and a recirculation manure pit. Slurry tanks with a required cover.	240 dairy cows. New building has to be decided.
Broilers	A production of 300,000 slaughter chickens annually. A loose housing system. Solid manure.	A production of 600,000 slaughter chickens annually.

Note: The farm size has been discussed with the Environmental Protection Agency.

3. Regulation

The following section provides a short description of the Danish ammonia regulation regarding livestock farms in relation to general ammonia requirements and the specific requirements for livestock farms near Natura 2000 sites. The general ammonia emission requirements (BAT emission levels) are different depending on the production size (AU), and so the large farms (tier 1 = 250 AU and tier 2 = > 750 AU) have a lower emission requirement than smaller farms (< 250 AU) even if they are not near Natura 2000 sites. Livestock farms (> 75 AU) have additional requirements relating to the ammonia emission depending on both the proximity to nature habitats (category 1, 2 and 3) and number of neighbouring livestock farms (see Table 7).

This division will form the basis of the analysis in the subsequent sections, in which the economic costs of additional ammonia regulation to protect Natura 2000 and other nature sites is analysed in relation to general ammonia requirements applicable to all farms. The general ammonia requirements include the use of a BAT (Best Available Technology) and emission levels, which are below the emission levels found in the reference technology for that type of livestock production (MST, 2016). The economic calculation will be based on a selection of technologies, which are able to meet the emission requirements for the expansion of the selected case farms. More details on the regulatory setup can be found in the legal sub-report by Anker and Baaner (2017).

Table 7. Overview over regulation requirements for different categories of nature

Require-ments	Ammonia sensitive area in DK (%)*	BAT General emission require-ments	Emission analysis	Emission requirement is based on	Cumulative approach (livestock farms nearby)
Category 1 Natura 2000	2.1	X (> 75 AU)	Specific emission requirement based on national limit	Total deposition for whole farm	X
Category 2 outside Natura 2000	1.1	X (> 75 AU)	Specific emission requirement based on national limit	Total deposition for whole farm	
Category 3 outside Natura 2000	2.1	X (> 75 AU)	Specific emission requirements might be set by municipalities	Total deposition from farm after expansion plus background deposition in relation to critical load locally.	
Outside category 1-3	94.7	X (> 75 AU)	No additional requirements	-----	
Total	100				

Note: The area included is the direct ammonia sensitive nature and not the area where there might be an impact on the permits. The total ammonia sensitive area is almost 258,000 ha.
Source: *Levin and Nygaard (2017).

3.1. The Previous Regulation System

3.1.1. General requirement

When a farmer wants to establish, expand, or rebuild a livestock installation, a permit is needed. According to the rules from before 1st of August 2017, small farms (15-75 AU) would have to apply a BAT technology to be allowed to expand, and other farms (over 75 AU) would have to apply BAT technology and a further 30 per cent emission reduction compared with the emission from the 2005/2006 emissions from the reference technology for expansion (see Appendix A). These levels are translated into BAT standard emission requirements (see later). The emission requirement related to BAT is for the whole farm, and so the farmer can choose whether the changes should involve the whole farm or only the expansion.

The emission requirement for the existing production can vary, but the requirement will be based on an assessment of the possible emission levels based on current technology. A large change of the current production system will require a new permit for the existing production. A re-evaluation of the permit typically takes place 8 years after it is issued (MST, 2017c).

With respect to slurry storage, the requirement is that a solid cover is present. This can be a natural cover (a crust), which needs to cover the whole slurry tank. In other cases, the application of straw etc. is required. In some cases (e.g. pig farms), a solid cover in the form of a tent or a floating lid is required as the natural cover is not sufficient. A logbook on the conditions of the cover has to be kept on the farm and notes have to be taken every month. The storage facility is examined every 10 years (MST, 2017c).

With respect to application, the requirement is that slurry applied in the spring before a crop is injected, and otherwise trailing hoses can be used. Injection is required also on grass fields (feed and seed), but e.g. not on winter wheat or winter oil seed rape. Broad spreading is not allowed. Only very limited application from harvest to November (selected crops and conditions) is permitted, and no application from November to February 15th is allowed. Technologies (e.g. acidification in the stables) (see technology list) can be used so that using a trailing hose is allowed instead of injection.

BAT Technology

The BAT requirements refer to the best available technology (BAT), which the farmer necessarily needs to include in the project plan in order to get an approval of the project. The BAT technologies are found on the technology list produced by the Environmental Protection Agency, and the technologies have both a certified effect on NH_3 emissions and are perceived as having an affordable level of costs (Jacobsen, 2012; MST, 2017b). For each technology, a description ('teknologiblade') has been made, stating the efficiency (ammonia reduction) and the cost of using this technology. The cost estimation is based on an average implementation of the BAT technology. The idea is that the local regulator does not need to carry out an assessment of the cost levels every time an application is made although in practice, there will be variations in the implementation costs for the selected technologies.

Based on these criteria regarding efficiency and costs, the Environmental Protection Agency has decided on required emissions levels for different farm types (BAT emission levels). Technologies costing more than 100 DKK/kg NH_3-N or 1 per cent of the total production costs are considered too expensive, and therefore are not included (Jacobsen, 2012) and for finishers, a level of 8 DKK (1.1 euros) per finisher has been set as the cut-off level. As the cost per unit decreases with size, the BAT emission levels have been set so that the allowed emission levels are lower for larger than smaller farms. In doing so, the actual costs per unit is roughly the same across sizes of pig and dairy farms. This standard requirement is to give the applicants a clear idea of the accepted emission levels. In some selected cases, the detailed Natura 2000 requirements can actually be lower than the standard BAT requirements (see section 5). The emission level required to fulfil the BAT emission levels is the baseline for the economic analysis in this report, since it applies to almost all livestock farms independent of their proximity to ammonia sensitive nature areas.

Table 8. BAT standard emission requirements for stables (Kg NH_3-N/animal)

	Max cost (DKK/NH_3-N)**	75-250 AU	250-750 AU*	> 750 AU
Finishers	100 (8 DKK/finisher)	0.30	0.30-0.21	0.21
Dairy cows	40	7.31	7.31-6.3	6.3
Broilers (35 days) (per 1000)*	100	11.9	9.9	

* The limits are from 0-200 AU and over 200 AU.
** The cost should be max 1 per cent of the total production costs.
Source: MST (2017c).

3.1.2. Nature and habitat requirements (category 1-3)

The further emission requirements related to Natura 2000 depend on the habitat and the number of other emissions (neighbours). As noted in Figure 3, there are 3 categories of "ammonia sensitive" habitats, where the category 1 nature can tolerate the lowest deposition. Only category 1 nature is located inside Natura 2000 sites. The calculations for the case farms are mainly related to the category 1 requirements. The total nature area within the three categories in 2015 was a total of 136,251 ha in category 1, 51,043 ha in category 2, and 104,040 ha in category 3, or around 290,000 ha in total (Nygaard & Bladt, 2015).

Category 1 habitats	**Category 2 habitats**	**Category 3 habitats**
The following habitats if located <u>within</u> a Natura 2000 site: 1. Areas with one of the 43 Annex I habitats considered sensitive to ammonia deposition – no size threshold applied 2. Heaths and dry grasslands protected by the Nature Protection Act § 3.	The following habitats located <u>outside</u> Natura 2000 sites: 1. Raised bogs 2. Lobelia-lakes 3. Heaths above 10 ha 4. Dry grasslands 2.5 ha.	The following habitats located <u>outside</u> Natura 2000 sites: 1. Other areas with heath, bog/moor or dry grassland protected by the Nature Protection Act § 3. 2. Old grown forests fulfilling the criteria for being sensitive for ammonia deposition.

Figure 3. Definitions of the different categories of habitat used in the Danish livestock regulation

Note: In category 3, only some of the areas are defined as ammonia sensitive.
Source: Anker and Baaner (2017).

Table 9 shows the maximum total ammonia deposition (stable and storage) in the area near the farm under consideration for an approval to expand or rebuild. The allowed ammonia deposition is dependent on whether there is any protected nature near the farm and the existence of neighbouring animal farms. The lowest total nitrogen deposition from a farm is permitted in category 1 nature areas, which are defined as nature types within Natura 2000 areas. In the case of proximity to Natura 2000 sites, the presence of neighbouring farms further decreases the amount of total allowable nitrogen deposition and will thus reduce the allowed ammonia emissions from the farm in question.

The background for the levels was that the total deposition (not additional deposition) should not exceed 1 kg N/ha/year. To be on the safe side, the level of 0.7 was introduced by the Agency, and at the same time, it was included that if the farm had one livestock neighbour causing a deposition of e.g. 0.3 kg N/ha/year, the farm could only have a deposition of 0.4 kg N/ha/year (see Table 9). The level was further reduced with two neighbours to ensure that the 1.0 kg N/ha/year level was not exceeded (see also Fredslund et al., 2017; Tegner & Baaner, 2017).

For category 3 nature, the limit for the deposition is the additional deposition from the farm based on the expansion of the farm (additional deposition approach). In the assessment made by the municipality, they look at the baseline deposition and the additional deposition from the farm. It should be noted that the deposition limit in relation to category 1 and 2 is the total deposition from the farm applying (both old and new buildings), whereas in case of category 3, it is the additional deposition compared to the situation before changes on the farm. For category 3, the allowed additional deposition requirement has to be over 1 kg N/ha and so the requirement cannot be very small (< 1 kg N/ha/year), which could prevent an expansion. The municipality looks at the critical load and the existing baseload including the emission from the existing farm. Analyses show that where municipalities set a limit they often use 1 kg N/ha (MFVM, 2017).

The base deposition in Denmark has been reduced from 17 kg N/ha in 2006 to 13 kg N/ha in 2015. As shown in Appendix F, the largest values are found near the German border and the deposition in e.g. Aabenraa is 19 kg N/ha in 2015. In a number of cases, the allowed additional deposition could therefore be 2-3 kg NH_3/ha or even more as the critical load can be 20 kg N/ha depending on the type of nature.

As shown, the number of neighbouring livestock farms influences the allowed emission based on the so-called accumulation approach. The livestock stables or installations included in the calculation depend on the size of the farms. The larger the farm, the larger the distance included, and so for neighbouring farms just over 15 AU, the circle from their farm is only 200 metres, whereas for farms with over 150 AU, it is 500-1,000 metres. For farms with more than 500 AU, the distance is based on a more detailed calculation (see Appendix A).

Table 9. Types of ammonia sensitive nature and allowed maximum deposition of nitrogen in relation to the number of neighbours (kg N/ha/year)

		0 neighbours	1 neighbour	>1 neighbour
Nature type	**Characteristics**	Total deposition allowed from farm (kg N/ha/year)		
Category 1	Within Natura 2000 area	0.7	0.4	0.2
Category 2	Outside Natura 2000, sensitive grassland > 2.5 ha (see Figure 1)	1	1	1
Category 3*	Outside Natura 2000, sensitive grassland etc. > 0.25 ha	(≥ 1 kg)	(≥ 1 kg)	(≥ 1 kg)

*Parentheses imply that decision on threshold depends on the assessment made by the local municipality. The assessment looks at the baseline deposition and the additional deposition from the expansion compared to the critical load (kg N/ha/year). The deposition calculation includes stable and storage.
Source: MST (2017b)

The larger distance used for larger livestock farm is to reflect that larger livestock farms will have an impact on the total ammonia deposition in a larger area. The distance is calculated from the centre of the buildings. The neighbour's emission is not directly included in the calculation for the farm applying, but the limits are lower if there is a neighbour as described above. In other words, a neighbour is only included in the calculation if the circle from his farm based on the size of the production crosses the radius from the farm increasing the production (see Anker and Baaner, 2017). In that respect, a large farm nearby can prevent further expansion on a farm.

It could be said that the total deposition from all the farms in an area only indirectly decide the allowed emission levels for the farm increasing the production. The actual total deposition on the nature sites in the area from all the farms (including emissions from other countries) in relation to the critical load for the specific nature located near the farm is not a key parameter in Denmark in relation to category 1, as the protection is based on a total deposition from the farm. In the case of category 3, the municipalities use maps showing the calculated deposition and relate that to the critical load locally, which would typically be between 10-25 kg N/ha (Nielsen et al., 2013).

3.1.3. Permits issued per year

The Environmental Protection Agency expects to receive 400 applications for extensions on livestock farms per year in the coming years, of which 320 are expected to be implemented (see Table 10) (Mikkelsen & Albrektsen, 2017). This level of applications is less than the current level of cases and decisions, as there were around 860 decisions last year, and around 400 decisions in the first 6 months of 2017 related to (§ 11 and § 12) covering farms over 75 AU.

There is some uncertainty regarding the actual use of environmental technologies in relation to fulfilling the requirements when increasing the size of the livestock production. Compared to previous projections (Hansen et al., 2014), the use of technologies in the stables (air scrubbers, acidification, and cooling) is now assumed to be somewhat lower than previous estimates

(Mikkelsen & Albrektsen, 2017). The present estimations are based on 100 applications from livestock farms that have been given permission to extend their livestock production, and the sample is perceived as representative for the 150 applications from 2013. Around 63 per cent of all applications are linked to larger farms (over 250 AU after expansion).

Based on this, it is expected that only 22 per cent of all applications include new housing environmental technology, like air scrubbers, cooling, acidification etc. (Mikkelsen & Albrektsen, 2017). In these technologies, change in feeding, storage, and application in the field is not included. It is expected that the share using housing environmental technology will increase (see Appendix C), but as mentioned, the uptake of environmental technology in 2020 is lower than previously expected and this has also increased the expected emission levels in 2020. The environmental technologies included in the overview are technologies applied inside the stable, so it could indicate that more farms have been able to deal with the cheaper options of changes in feeding, choice of low emission stables (flooring), and solid cover on their slurry storage. It is estimated that the total number of AU in the applications is around 90-100,000 AU/year based on the authors' assumptions regarding the amount of average applications based on information from The Environmental Protection Agency. The production included in the permits is the full production after the expansion.

The numbers seem to indicate that many farms seek to carry out the expansion of their farms on a site where large reduction requirements on ammonia emission are not required. In that sense, the impact of expansion on nature should be reduced.

Table 10 provides an estimate of the possible distributions of permits related to Natura 2000 and category 1 per year based on the adaptation of technologies described above. It is estimated that 10-15 per cent of all permits are linked to category 1 and Natura 2000 requirements as they are expected to have to implement new technology. As mentioned before, in many cases, larger farms over 750 AU will also have to use new technology to fulfil the stricter requirements. On the other side, many farms (especially dairy farms) can deal with the BAT requirements through choice of flooring and cover on slurry storage.

Based on these assumptions, it is likely that the annual number of applications, where the strictest emission requirements (category 1 with 0-2 neighbours) have to be fulfilled, might only constitute 30-40 applications/year or around 6-9,000 AU/year (6-10 per cent of the AU in the applications). In a number of cases, applications are not made if the requirements are too costly to fulfil. It can therefore be assumed that the number of applications near Natura 2000 sites with two livestock neighbours are limited. As mentioned earlier, the Environmental Protection Agency has no direct overview of the technology used and the number of permits given to farms near Natura 2000 sites, but such an overview would have been useful in this analysis.

Table 10. Rough estimate of distribution of livestock permits per year

	Applications/year	Share of applications (%)	Production involved in permits/year (AU/year and AU/application)	Share of animal units (%)
Total applications	400			
Applications realized	320	100	94,000 294 AU/app	100
- Stable, feeding, and storage	249	78	73,320 294 AU/app	78
- Additional technology in stables	71	22	20,680 294 AU/app	22
Applications related to § 12 (over 250 AU)	200	63	70,000 400 AU/app	75
Applications related to § 11 (75-250 AU)	120	37	24,000 200 AU/app	25
General NH_3 requirement (BAT) and category 2+3	(280-290)	(85-90)	85,000-88,000 302 AU/app	90-94
Additional Natura 2000 requirements (category 1)	(30-40)	(10-15)	6-9,000 210 AU/app	6-10

Note: Only farms over 75 AU are included in the table. Farms under 75 AU only have to fulfil BAT requirements (see Appendix A). The average size of application is set at 400 AU for § 12 and 200 AU for § 11. The distribution between general requirement and Natura 2000 is based on the assumption that most Natura 2000 permits (related to category 1) require new technology in the stables (10-15 per cent of all applications) and the rest relates to large farms (§ 12) not very close to Natura 2000 sites. In total 857 decisions were made related to § 11 and § 12 in 2016 (Landbrugsavisen, October 28th, 2017).
Source: Mikkelsen and Albrektsen (2017) and own assumptions regarding share of Natura 2000 applications.

Levin and Nygaard (2017) have found that the applications, which include environmental technologies (buildings and storage) for expansion in 2007-2015, are mainly (70 per cent) on larger farms with more than 75 AU. In other words, the owners of the larger full-time livestock farms are the ones who want to expand. As noted before, 11 per cent of the applications were from farms close to category 1 nature, which is not too far from the assumptions made above. Analyses also show that farms located in places with no or few restrictions (few livestock farms nearby) were more likely to increase their production from 2005-2015 (Jesper Bak, Aarhus University, personal communication, 2017). The analyses show that 80 per cent of all farms that expand are situated where the reduction requirements are limited (ibid).

3.2 The Future Regulation System

3.2.1. The regulatory approach

The analyses in the report are based on the old regulation system, but it can be worthwhile just to give a short description of the future regulation setup and some of the implications. In the new regulation, there is a change from emission per animal to emission per area or animal place (see Retsinformation, 2017). This can also help when emission levels are compared to the emission levels in The Netherlands and Germany as they are also based on the emission per animal unit or place unit and not per animal.

From August 1st, 2017, the permit application is considered in regards to the general ammonia reduction requirements and reductions by the use of the best available technology (BAT) for farms emitting more than 750 kg NH_3-N/year (BAT requirements). (MST, 2017c; Folketinget, 2017). According to the preparatory remarks to the law, the limit of 750 kg NH_3-N/year is roughly equivalent to the limit imposed in the present § 11 regulation (over 75 AU) (see Appendix A). As before, there is no requirement on farms with less than 75 AU (§ 10) as the BAT requirements only apply for farms over 75 AU. The limits stated here are always for the total production after the expansion and not for the size of the production before expansion. In effect, there is no regulation, which focusses on the emissions from existing farms, which do not change their size of production, but over time, most farms will have applied to expand the farm. It is assumed that farms will not divide their activities into smaller units to avoid regulation requirements. Just as before, livestock productions under 100 m^2 of production area (stables) (15 AU) do not need to fulfil the BAT emission requirements.

The 30 per cent reduction requirement compared to the 2005/2006 emission level (based on the reference technology) is now changed and included in the requirements. The idea is that in the future, the BAT requirement per animal place or m^2 stable will give the same emission level or lower than a requirement based on the 2005/06 reference technology minus 30 per cent, and therefore the requirement is not needed anymore. An emission of 3,500 kg NH_3-N/year is equivalent to 900 places for sows or 3,000 places for finishers (from 30 kg) or 85,000 places for broilers.[1] In comparison, the IPPC limits (IE limit) are 2,000 places for finishers.

The new regulatory system is different as the focus is on the emission in the stables assuming a standard emission from the slurry storage. In case the applicant chooses to reduce emissions from storage, this is included in the calculation of the emission from the stables. The next section will provide a brief overview of how the new regulation setup will change the allowed emission levels.

3.2.2. The allowed emissions

The implication of the new system for production permits is that the emission in the future will follow the unit of space in the stables ('stipladsmodellen') and not, as today, the unit of animals. An overview of the emission per unit of space (m^2 and place) can be found in Kai and Adamsen (2017) (see Table 11). The production area is defined "as the area to which animals more or less have access to all the time and so would deposit manure even if manure is not deposited there" (Adamsen et al., 2016). In the change, it is also the intention to reduce the number of emission levels for each type of animal.

1 Bendt Ib, Landbrug & Fødevarer, personal communication, 2017, verified by The Danish Environmental Protection Agency.

Table 11. Conversion from emission per animal to emission per place unit

		Emission 2017 (kg NH_3-N /animal) (ex storage)[1]	Production-area/animal (m^2/animal)	Product-ion/place unit/year	Emission * (NH_3-N/m^2)	Emission * (NH_3-N/animal place)[2]
Finishers	33 % drained floor and 66 % slatted floor.	0.405	0.65	3.71	2.3	1.50
Dairy cows	Cubicles with slatted flooring and a recirculation manure pit	10.61	7.99	1.0	1.34	10.71
Broilers (*1000)	A loose housing system. *) 35 Days	0.0046	0.054	8.69	0.74	0.04
Hens	Free range hens indoor	0.2913	0.11	0.92	2.30	0.26
Sows 1	Gestation pens	1.67	1.25	1.0	1.3	1.63
Sows 2	Farrowing section	0.72	1.09	1.0	0.66	0.72

Note: These are not new requirements, but merely conversion from emission per animal to emission per m^2 or animal place.
Note: Finishers (p. 17+31), Cows (p. 3+27), Broilers (p. 18+ 32), Hens (p. 21+ 32), Sows (p. 15+ 31).
*) The proposed emission level is used.
1) The emissions are only from the stables and not the storage. The emissions including the storage emission are (NH_3-N/animal): 0.443; 12.5; 0.0046; 0.2913; 1.95; 0.84).
2) The emissions including the storage emission are (NH_3-N/place) (p. 45): 1.65; 12.99; 0.06; 0.28; 1.93; 0.85).
Source: Kai and Adamsen (2017)

Note that change in feeding is not currently an approved 'technology', which can be used to reduce ammonia emission in the new regulatory approach.

A new set of limits for emissions per m^2 and animal place is established. Again, it might not be a direct translation of the emission per animal, but the overall principle is that the emission requirements are the same. Based on Table 12 this seems to be the case, although the reduction requirement compared to the baseline emission for the different types of livestock and levels are not all the same.

Table 12. Emission requirements in previous and new regulation

		Previous regulation	Previous regulation	Previous regulation	New regulation	New regulation	New regulation
		Emission factor 2017	Required at 250 AU 1)	Required at 750 AU	Emission Factor 2017 2)	Required < 250 AU 2)	Required > 750 AU 2)
		Kg NH_3-N/animal	Kg NH_3-N/animal	Kg NH_3-N/animal	Kg NH_3-N/m^2	Kg NH_3-N/m^2	Kg NH_3-N/m^2
Finishers	33 % drained floor and 66 % slattered floor.	0.405	0.319 (-21 %)	0.223 (-55 %)	2.3	1.62 (-30 %)	1.06 (-54 %)
Dairy cows (no heifers)	Cubicles with slatted flooring and a recirculating manure pit.	10.61	7.31 (-31 %)	6.30 (-41 %)	1.34	0.67 (-50 %)	0.67 (-50 %)
Broilers (*1000)	A loose housing system. *) 35 Days	0.0046			0.74	0.57 (-23 %)	0.57 (-23 %)

1) Bat Tier level 1: At around 250 AU (for finishers it is 210 AU and broilers 100 AU)
2) Emissions are excluding emissions from storage
Note: Emissions requirements from 250 to 750 AU for finishers are linear.
Sources: Kai & Adamsen (2017: p. 60+64); Kristoffer Jonassen, Environmental Protection Agency, personal communication, 2017; and own calculations.

4. Possible Technologies and Costs

The purpose of this section is to describe the different likely technologies that can be chosen to reduce emissions, and then to calculate the cost of implementing this technology. The current technology list and the official effects on ammonia emissions can be found on the Environmental Protection Agency's website (MST, 2017a). The overview does not include all technologies, but the ones that are the most likely to reduce the ammonia emissions on the farms.

The standard norm values for the ammonia emissions are not used directly in the application system (husdyrgodkendelse.dk) as the system focusses on the ammonium N (TAN), where the emission is a share of the ammonium N, not the total N (Poulsen, 2016). The values used in the case analysed are therefore different from the norm values. The newest changes and results regarding ammonia emissions from stables are not included in the calculations (Kai et al., 2017).

In this section, the first part (4.1.) describes the technologies, and the second part describes the costs. The calculations are summarized in section 4.3.

4.1. Possible Technologies

4.1.1 Different types of stables and flooring

The type of floor affects the surface area and temperature of the slurry, which again affects emissions of ammonia. Surfaces with more solid floor have a reducing impact on these parameters but also increase the amount of nitrogen content in the slurry compared to a fully drained floor (MST, 2011a).

The emission level was 0.47 NH_3-N/finisher based on emission from drained floor from 2008-09 (MST, 2011a). However, the reference stable today has one third drained floor and two-thirds slatted floor with an emission of 0.39 kg NH_3-N/finisher (2016/17 norm levels (Poulsen, 2016)), which is also used in the case analysis later. The emission from floors with part splits and part drains has been reduced over time as the feeding efficiency over time has changed. So, over time there has been both a change in reference technology and a change in the emissions per animal for the same housing system. Floors with 25-49 per cent solid floor emit 17 per cent less ammonia than the reference stable with partly drained/partly slatted floor, while floors with 50-75 per cent solid floor emit 34 per cent less ammonia than the reference stable (MST, 2011a).

The reference system for a dairy cow stable is assumed to be a cubicle stable and split floor, with channels underneath the drained floor, or flushing ('bagskyl') as in The Environmental Protection Agency's descriptions from 2011 (MST, 2011b). The emission used here is 11.2 kg NH_3-N, based on the Environmental Protection Agency's calculation, whereas the standard figures for emission is 10.61 kg NH_3-N/cow (Poulsen, 2016).

Dredgers for dairy cow barns with standard flooring include dredgers that push the manure on the floor into canals below the slattered flooring or into a shaft (MST, 2010a). This way, manure is kept away from the slattered floor surfaces, reducing the amount of ammonia emitted (DCA, 2016). With the lower amount of ammonia emissions, more ammonia nitrogen is left in the manure applied to fields (MST, 2010a).

A stationary dredger can be pulled by a cable in a pull station along the passage area. A robotic dredger automatically returns to a charging station for recharging after cleaning. Unlike a stationary dredger, it can go around the cows if necessary and can be installed to go to the parts of the stable in most need of cleaning. Both types of dredgers can be used in both existing and new barns. In barns with slatted floor and recirculation manure pit (the reference floor type), the floor is cleaned 6 times a day, and this achieves an ammonia reducing effect of 25 per cent from the stable (MST, 2010a). In the following sections, the reduction used is 25 per cent of the ammonia emission of the 11.2 kg NH_3-N/dairy cow, that is, 2.80 kg NH_3-N/dairy cow.[2] This reduction only entails the effect in the stable and manure storage tank.

[2] Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017 (case calculations); and Table 13

According to the Environmental Protection Agency (MST, 2010b), dairy cow stables can be constructed with solid floors with drainage, where dredgers clean the floor several times daily. This type of stable and practice reduces ammonia emissions from the stable by 50 per cent compared to the reference stable (cubicle stable and split floor with channels underneath the drained floor or flushing) (MST, 2010b). With a per cow emission of 11.2 kg NH_3-N (see Table 12), the calculated reduction is 5.6 kg NH_3-N.

For broilers, there is only one stable type in operation in Denmark with regards to slaughter chickens or broiler chickens. The stable has deep litter and a direct application rate of litter of 15 per cent as well as feed 3 in the technology description. (MST, 2011c). The system entails an ammonia emission of 6.4 kg/1,000 animals, which is used in the case analysis.[3]

4.1.2. Slurry acidification

Slurry acidification entails the addition of sulphuric acid to slurry in the stable which lowers the pH of the slurry to 5.5-6.0. In this way, the extent to which nitrogen in the slurry is converted to ammonia is reduced. Pig slurry typically demands 4-6 kg of sulphuric acid/ton of slurry to lower the pH to 5.5-6.0 while cattle slurry demands 5-7 kg/ton (MST, 2011d; 2011e; 2014). The systems entail additional electricity and other operational costs besides capital costs.

For finishers, the effect depends on the stables where it is used (Kai et al., 2016; MST, 2011d; DCA, 2016). The reduction in ammonia emission from the stable when using 33 per cent slatted/67 per cent drained floor + slurry acidification is set at 64 per cent (DCA, 2016; Kai et al., 2016). The additional reduction effect of slurry acidification is lower, when the floor is partially solid (50-75 per cent solid and 20-49 per cent solid respectively), since the floor type already reduces emissions from the slurry, but the total effect is still expected to be 64 per cent (Kai et al., 2016).

The emission has been calculated to be 2.3 kg NH_3-N/m^2/year (drained floor) and so the emission is 0.83 kg NH_3-N/m^2/year when acidification is used (Kai et al., 2016). In another calculation, DCA (2016) concludes that acidification reduces the total ammonia emission per finisher from 25.7 to 10.3 kg NH_3-N/AU or from 0.66 to 0.26 kg NH_3-N/finisher based on 39 finishers/AU (60 per cent reduction). The effect is here 0.4 kg NH_3-N/finisher, whereas the straight forward calculation with an effect of 64 per cent on the total emission gives an effect of 0.25 kg NH_3-N/finisher (final level is 0.39*0.36 = 0.14 kg NH_3-N/finisher). The reason for the difference is that the initial emission used in DCA (2016) include the storage and application (0.66 kg NH_3-N/finisher), and therefore the total effect is also larger.

In relation to the new regulation, the baseline emission for finishers when using acidification is reduced to 1.48 kg NH_3-N/m^2 from slurry and 0.83 kg NH_3-N/m^2 from the floor. The total emission effect is 2.31 kg NH_3-N/m^2/year (Kai et al., 2016) for the reference technology floor.

[3] Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017.

For dairy cows, slurry acidification will reduce ammonia emissions by 50 per cent in stables with cubicles and split floor and channels (DCA, 2016). The reduction in stables with drained floor with dredgers will be higher and could be around 75 per cent as the effect would be additive (50+25 per cent = 75 per cent) (Kai et al., 2016). When slurry acidification is used in a stable that already has low-emission floors, the additional effect of acidification is lower compared to the reference stable since both measures reduces ammonia emissions from the slurry itself. However, according to Kai et al. (2016), slurry acidification cannot be used in cow stables with cubicles and split floors with "line scraper" or deep litter stables with a mechanic mucking system.

The use of acidification can be combined with the product Smellfighter to reduce smell, which is also a key requirement in some permits. It could be noted that, today, there are few providers of the acidification technology for buildings as few Danish farmers have invested in acidification in stables in the past 1-2 years. Furthermore, there are indications that the use of acidification has been reduced in 2017 as farms can now apply the full economic optimum nitrogen amounts to fields and this has reduced the economic advantage of using acidified slurry in the field (Lyngsø, 2017).

4.1.3. Permanent cover on slurry tanks

Covering slurry tanks with a permanent, synthetic canvas cover reduces ammonia emissions compared to the solid layer of e.g. straw or a tent required by law. This reduces the emission from around 2 per cent to 1 per cent of the total NH_3 (MST, 2010c), where the emission without cover is around 9 per cent. The reduction is calculated to be around 1 kg NH_3-N/AU in the technology assessment mentioned above. This is equivalent to approximately 0.026 kg NH_3-N/finisher and 1.33 kg NH_3-N/dairy cow, based on 39 finishers and 0.75 dairy cows/livestock unit (AU). The measure is neither combined with slurry acidification nor cooling in the following analysis, since the additional effect of having a permanent cover when combined with acidification is expected to be limited although relatively similar (50 per cent) as stated above. On the other hand, acidification could reduce costs of cover (tent) on slurry tanks especially on pig farms, although this is not the case when closer than 300 metres from category 1 or 2 nature. An additional effect of a permanent cover is that the size of storage and the application costs can be reduced as rainwater does not take up space in the slurry tank.

4.1.4. Chemical air cleaning (air scrubbers)

Chemical air cleaning entails that air from the finisher stable is led by the ventilation system through a filter or vaporized water, both containing sulphuric acid. In this way, the ammonia in the air is transferred into liquid form. The liquid, containing ammonia and sulphur, can then be applied as fertilizer or stored in the slurry container. Chemical air cleaners do not reduce odours (MST, 2011f).

Chemical air cleaners reduce ammonia emissions by the following: in case of 100 per cent capacity of the ventilation system in the stable, the effect for the reference stables (33 per cent drained/67 per cent slatted floor) when using chemical air cleaning will be 89 per cent (DCA, 2016) for the two products MAC 1.0 and MAC 2.0. The ammonia reduction has been calculated to 0.33 kg N/finisher based on 100 per cent cleaning capacity. In the cost calculation, this amount of ammonia corresponds to a saving on N-fertilizer as it is assumed to be applied to fields (assuming a 75 per cent plant uptake). The sulphur collected is also applied as fertilizer. This corresponds to savings of 15 kg of sulphur fertilizer per hectare (Kai, 2017).

When using 60 per cent cleaning capacity, the ammonia reduction is 0.29 kg NH_3-N/finisher or 88 per cent of full effect, and in case of 20 per cent ventilation capacity, the effect on ammonia emission is only reduced to 60 per cent (DCA, 2016). In other words, the ammonia reduction capacity is not reduced as much as the overall cleaning capacity and therefore systems with less than full capacity could be more cost-efficient.

Chemical air cleaning can also be used in broiler barns and has an expected ammonia reducing effect of 75 per cent. Air from the stable's ventilation system goes through a filter irrigated with e.g. sulphuric acid. As in chemical air cleaning in finisher stables, ammonia (and sulphur) is collected in a liquid, which can be used as fertilizer. Like for finishers, part air cleaning can also take place in broiler barns. Throughout the production period, there will be a higher need for ventilation, and a lower capacity air cleaning system could thus be used for broilers. In these systems, the filters in the air cleaners may be filled with dust, so in order for the ventilation and air cleaning system to work and to maintain animal welfare, the filters need to be kept dust free (MST, 2011g). However, chemical air cleaning is not on the Environmental Protection Agency's technology list and will therefore not be considered further in this section.

4.1.5. Biological air cleaning

When using biological air cleaning in finisher stables, the air from the stable's ventilation system is led by a moist filter, irrigated with water. Organisms on the filter process the ammonia. The collected liquid contains nitrogen in ammonium, nitrite, and nitrate, which can be used as fertilizer and where about 50 per cent of the nitrogen is available to plants. The filter needs to be properly maintained and cleaned and work together with the ventilation system. Keeping the filter clean also helps reduce emissions of nitrous oxide. The air cleaning also reduces odours from the stable (MST, 2011h). An air cleaning system with a capacity to clean 100 per cent will in effect clean 88-89 per cent of the air in the reference system (DCA, 2016). Again, a lower capacity will reduce the efficiency of the air cleaning, but as shown before, part air cleaning based on 60 per cent and 20 per cent capacity can be cost-efficient as the ammonia reducing effect is only reduced to 93 per cent and 76 per cent of the full effect (DCA, 2016).

According to DCA (2016), air cleaning in stables, with partly solid floors, that use mechanical ventilation, requires additional valves in the ceilings. Partly solid floors also affect ammonia in the stable air compared to 33 per cent drained/67 per cent slatted floors (DCA, 2016). If air cleaning is combined with other technologies in the stable, the net combined effect on ammonia emissions depends on the reduction effect of the other technology and the effect can be calculated using the formulas in Kai et al. (2016).

4.1.6. Slurry cooling

With this measure, cooling cables are either moulded into the floor or placed on the floor in the slurry canals. A heating pump cools the slurry while the excess heat, in some stables, can be used for heating other stables e.g. on sow and piglet farms. In the base calculations, it is assumed that the finisher farm can use the heat or transfer it to other stables such as piglet stables, the farm house, or other buildings. In many cases, this will not be possible and then the costs of cooling will be much higher. The lower temperature of the slurry in the stable reduces ammonia emissions depending on stable system, animal type, and cooling effect. With this measure, there will be more nitrogen in the slurry in the tank and in the fertilizer in the fields, and thereby ammonia emissions from these sources are marginally increased. The increased nitrogen in the tank in the form of ammonia is available to plants when applied in the fields.

The relationship between cooling effect (X W/m^2) and ammonia reductions (per cent) is for stables with mechanical mucking $-0.008X^2 + 1.5X$ while it is $-0.004X^2 + X$ in stables with slurry channels (traditional system) (MST, 2011i). The analysis is based on 20 W/m^2, which is perceived to be the most commonly used. Using this effect and the formula above, the calculated effect on ammonia reductions is 18.4 per cent. According to Kai et al. (2016), these emission reduction relationships can be used for all types of pig stables. It is assumed that cooling will have no additional effect when combined with acidification.

4.1.7. Feeding practices

According to MST (2011j), reducing the crude protein content in finisher feed reduces ammonia emissions in the stable, tank, and from the field while having a marginal reducing effect on nitrate leaching from fields. The measure for finishers involves a lower amount of crude protein and potentially a phased feed composition where feed changes over time according to growth needs combined. The relative effects (per cent) are independent on stable type. In many cases, phase feeding will have lower costs than traditional feeding. Costs will increase when phase feeding requires a new feeding system to be established (MST, 2011j).

Over time, the use of crude protein has been reduced and so the option of moving from e.g. 157 g crude protein to e.g. 147 g crude protein is no longer an option for most farms, as today, the average is considered to be around 146 g crude protein/FU (DCA, 2016; Poulsen, 2016). This measure is therefore not included in the analysis.

Using less crude protein in feed to dairy cows is also an option, which has been used in recent years. The measure entails reducing the amount of crude protein in the dairy cow's diet, which reduces ammonia emissions from manure in the stable, storage, and the field while less nitrogen will be available for fertilizer purposes. Except for the change in diet, the measure necessitates feed analyses and planning and follow-ups (MST, 2010d). The crude protein content is lowered by reducing the amount of soy bean meal and rapeseed cake while increasing the amount of barley and beet pellets. The amount of fodder remains the same (MST, n.d.a). Over time, the use of crude protein has been reduced and so the option of reducing it further is now limited and would require new calculations to estimate the costs based on the 2016 feeding levels. This measure is therefore not included in the analysis.

It should be noted that changed feeding practice is not included in the technologies available under the new regulation system from August 2017. For more information see Kai and Adamsen (2017). The changes in feeding over time will be reflected in the "norm emissions" from that year, but there seems to be less incentive to further reduce the protein use unless it is included in the technology list later.

4.1.8. Heat exchangers for broiler barns

The heat exchanger uses warm, outbound, ventilation air to heat the inbound air, which aids in drying out the deep litter, thus reducing ammonia emissions by 30 per cent (ETA-Danmark, n.d.). For one broiler case farm of 300,000 broilers, one heat exchanger is needed and for 600,000 broilers two heat exchangers are needed.[4]

4.1.9. Combination of technologies

As discussed earlier, in some cases technologies can be combined to give a higher effect, however, the effects are not always additive so the combined effect is not always the sum of the two or more technologies used. In this section, we try to summarise possible combinations of technologies and to what extent they are additive or not based on Kai et al. (2016). In this section, the term 'chain effect' is used when the effect of a certain technology is a percentage of the emission from another technology.

Cooling of slurry and slurry acidification both influence the emission from the surface. It is therefore not expected that the effects are additive. In this case, the ammonia emission after acidification is very limited and so there is no effect of cooling.

The effects of slurry cooling and air cleaning are not additive as the air cleaning is an end-of-pipe technology. The combined effect is therefore based on a calculation of the chain effect so that the combined effect of cooling (30 per cent) and air cleaning (89 per cent) is 92 per cent (0.3 + 0.7*0.89).

4.1.10. Summary of technology options

Table 12 shows an overview of the technologies included in this analysis covering finishers, dairy cows, and broilers. As the table shows, there are a range of options for finishers and dairy cows, but not many options to reduce emissions from broilers. The table shows that the effects range

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from 7 to 90 per cent compared to the respective reference technology. In some cases, it will be possible to achieve even higher reductions if two technologies are combined, but as noted in section 3.3.8., the effects are seldom additive.

The distribution of the total pig and dairy production on stables with different types of new technology can be found in Table 4 and Appendix C. The tables show that cooling of slurry is the most popular technology on pig farms, whereas acidification is the most popular on dairy farms. For the production of piglets, air cleaning is the dominant technology.

Table 13. Overview of possible technologies and their emission reduction levels (emissions in stables only)

Type of livestock	Area	Technology	Emissions level (kg NH_3-N/animal)	Reduction relative to reference technology
Finishers	Stables 1)	100 % drained floor and 157 g/FE (2005/06 norm values)	0.50	+28 %
	Stables 1)	25-49 % solid floor (2005/06 norm values)	0,44	+13 %
	Stables 2)	100 % drained floor (2008/09 norm values)	0.47	+21 %
	Stables 2)	25-49 % solid floor (2008/09 norm values)	0.39	0 %
	Stables 3)	1/3 drained floor, 2/3 slatted floor and 146 g/FE (2015 norm values)	0.40	+3 %
	Stables 4)	1/3 drained floor, 2/3 slatted floor and 146 g/FE (2017 norm values)	0.39	**Reference technology**
	Stables 4)	25-49 % solid floor the rest is drained (2017 norm values)	0.32	-18 %
	Stables 4)	50-75 % solid floor the rest is drained (2017 norm values)	0.24	-38 %
	Solid cover 5)	Reference technology and solid cover on slurry tank (effect is 1 kg NH3/AU = 0,026 kg NH3/animal with 39 finishers/AU.	0.364	-7 %
	Slurry cooling 6)	Reference technology and slurry cooling	0.32	-18 %
	Slurry cooling + solid floor 6)	18.4 % reduction based on 0.32/finisher with 20-49 % solid floor	0.26	-33 %
	Acidification 6)	Reference technology and acidification in the stables	0.14	- 64 %
	Air cleaning 7)	Reference technology and chemical air cleaning (20 % capacity)	0.16	-54 % (0.89*0.61)
	Air cleaning 7)	Reference technology and biological air cleaning (20 % capacity)	0.11	-67 % (0.88*0.76)
	Air cleaning 7)	Reference technology and biological air cleaning (100 % capacity)	0.05	-88 %
	Air cleaning 7)	Reference technology and chemical air cleaning (100 % capacity)	0.04	-89 %

Dairy cows	Stables [8)]	Cubicles stable with split floor and channels/flushing. (2015 norm values)	10.61	**Reference technology**
		Cubicles stable with split floor and channels/flushing. (MST case calculation) *	11.2	
	Stables [9)]	Cubicles stable with split floor and channels/flushing and dredgers	7.95	-25 %
	Stables [10)]	Cubicles stable with low emission floor and dredgers	5.3	-50 %
	Acidification[7)]	Cubicles stable with split floor and channels/flushing and acidification	5.3	-50 %
	Acidification[11)]	Drained floor with dredgers and acidification	2.7	-75 %
	Solid cover [5)]	Reference technology and solid cover (1 kg NH3/AU= 0.75 kg NH3/dairy cow)	9.86	-7 %
Broilers (x1000)		Deep litter, 15 % direct application and feed level 3 (35 days). (MST case farm calculation) (incl. storage)	6.4	
		Deep litter, 15 % direct application and feed level 3 (35 days). (2016 norm values)	4.8	Reference technology
	Heat exchange	Heat exchange	3.4	-30 %

*) Note: The standard norm values for the ammonia emission are not used directly in the application system (husdyrgodkendelse.dk) as the system focusses on the ammonium N (TAN), where the emission is a share of the ammonium N, not the total N. The values used in the case analysis are therefore different from the norm values. Sources: [1)] Aaes et al. (2009, p. 79); [2)] MST (2011a); [4)] Poulsen, H.D. (2015, 2016 and 2017). Standard values for nutrient content; [5)] Based on MST (2010c) (Own calculation of storage effect); [6)] DCA (2016) & Kai et al., (2016); [7)] DCA (2016); [8)] Poulsen, H.D. (2015) Standard values for nutrient content (p. 6); [9)] MST (2010a); [10)] MST (2010b); [11)] Kai et al. (2016): [12)] ETA-Danmark (n.d.)

4.2. Cost of Technologies

The following section presents the costs of technologies described in the previous section. Costs are primarily based on cost calculations carried out by University of Aarhus (DCA, 2016) and otherwise the Environmental Protection Agency's background economic and technology sheets and other sources as stated (MST, 2011a-o). The costs are presented for different farm sizes as well as scaled to the relevant case farm size (185 AU for finishers). For broilers, the options are more limited and so the whole analysis is focussed on the case farm.

The cost calculations show the additional cost of the technologies described compared to the relevant base technology for the animal type. The cost estimates include the investment cost converted to an annual cost for the lifespan of the investment. The operation and maintenance cost (O&M) are then added together with saved costs. These cost components together with savings on fertilizer make up the calculated net cost of the measure. The ammonia reduction of each technology is based on Table 12 in the previous section, the required reduction based on the reference emission, and the required emission level provided by the Environmental Protection Agency using the calculation tool in husdyrgodkendelse.dk.[5]

Costs have been converted to 2017-DKK based on the Danish Energy Agency's BVT-deflator[6], so prices from 2016 have been increased by 1.8 per cent. Detailed information on cost calculations can be obtained from the authors. Reduced ammonia emissions from slurry are assumed to correspond to a reduction in the need to apply mineral N fertilizer. The amount of N fertilizer saved is calculated by assuming a plant uptake of ammonia N of 75 per cent in pig slurry, 70 per cent in dairy cow slurry, and 45 per cent in slaughter chicken with deep litter (Agricultural Agency, 2017) and is valued with the price of N fertilizer at 7.96 DKK/kg N, which is the average costs during 2012-2016 (SEGES, 2017a). The hourly wage rate is 195 DKK based on SEGES (2017b). When calculating the annual costs, an interest rate of 4 per cent is used.[7] The lifespan of the assets in the calculations are between cases 10-25 years. The values are in DKK, but can be converted using 1 euro = 7.45 DKK.

4.2.1. Cost for finishers

In the following, it is assumed that half of the case farm's finishers are situated in an old stable, where floor type cannot be changed, whereas the other half, the expanded part, of the farm will be situated in a new farm where floor type can be chosen upon construction. The same is the case for slurry cooling.

Floor types

25-49 per cent solid floors

Low emission flooring is only relevant for the part of the production that is expanded and therefore situated in the new stable, and costs based on MST (2009) are shown in Table 14, calculated to 2017-DKK. The lifetime of the flooring is 15 years (op. cit.). The ammonia reduced in the new stable is calculated to 0.07 kg NH_3-N/finisher (17 per cent). This includes an additional ventilation to avoid higher ammonia emissions, which is included as an additional investment. It is also assumed that there will be a need for additional labour effort to keep the pig pens clean to avoid higher ammonia emissions. The O&M costs therefore consists of labour costs for additional cleaning of the pig pens based on an extra half hour of labour per pen for three months (MST, 2009).

[5] Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017.
[6] Available here: https://ens.dk/service/fremskrivninger-analyser-modeller/samfundsoekonomiske-analysemetoder
[7] https://www.fm.dk/nyheder/pressemeddelelser/2013/05/ny-og-lavere-samfundsoekonomisk-diskonteringsrente/

Table 14. Summary of flooring costs different farm sizes, 2017-DKK

25-49 % solid floors	Unit AU	75	150	250	500	750	950	185[2]
Ammonia reduction[1]	%	17 %	17 %	17 %	17 %	17 %	17 %	17 %
Ammonia reduction[1]	kg NH_3-N/animal	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Ammonia reduction	Kg NH_3-N/farm/year	196	392	653	1.305	1.958	2.480	483
Investment costs	DKK/farm/year	6,817	13,634	22,724	45,448	68,172	86,351	16,816
O&M	DKK/farm/year	6,031	12,060	20,101	40,201	60,302	76,382	14,874
Total costs	DKK/farm/year	12,848	25,695	42,824	85,649	128,473	162,733	31,690
Fertilizer value[1]	DKK/farm/year	1,169	2,338	3,896	7,793	11,689	14,806	2,883
Net costs[1]	DKK/farm/year	11,679	23,357	38,928	77,856	116,784	147,926	28,807
Net costs/finisher	DKK/finisher/year	4	4	4	4	4	4	4
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	60	60	60	60	60	60	60

1. With no other technology.
2. The case farm can only install new flooring in the new stable building. The assumed costs for the case farm (185 AU) have been calculated proportionally to the farm size.

Source: MST (2009)

50-75 per cent solid floors

As for 25-49 per cent solid floors, 50-75 per cent solid floors are only relevant for half of the production size. Here the ammonia reduction is calculated as 0.13 kg NH_3-N/finisher (Table 15). As above, extra ventilation and labour costs are included (1 hour per pen for three months) (MST, 2009). The lifetime of the flooring is 15 years (op. cit.). The costs for different farm sizes are shown in the table below, assuming flooring as the only technology.

Table 15. Summary of flooring costs for different farm sizes, 2017-DKK

50-75 % solid floors	Unit AU	75	150	250	500	750	950	185[2]
Ammonia reduction[1]	%	34 %	34 %	34 %	34 %	34 %	34 %	34 %
Ammonia reduction[1]	kg NH_3-N/animal	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Ammonia reduction	kg/farm/year	392	783	1,305	2,611	3,916	4,960	966
Investment costs	DKK/farm/year	7,279	14,559	24,264	48,529	72,793	92,205	17,956
O&M	DKK/farm/year	11,846	23,693	39,488	78,975	118,463	150,053	29,221
Total costs	DKK/farm/year	19,126	38,251	63,752	127,504	191,256	242,257	47,176
Fertilizer value[1]	DKK/farm/year	2,338	4,676	7,793	15,586	23,378	29,613	5,767
Net costs[1]	DKK/farm/year	16,788	33,576	55,959	111,918	167,878	212,645	41,410
Net costs/finisher	DKK/finisher/year	6	6	6	6	6	6	6
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	43	43	43	43	43	43	43

1. With no other technology.
2. The case farm can only install new flooring in the new stable building. The assumed costs for the case farm (185 AU) have been calculated proportionally to the farm size.

Source: MST (2009)

Slurry handling technologies

Stable acidification

Stable acidification is assumed to only be relevant to install in the new stable. Here, the reduction in ammonia is calculated as 0.24 kg NH_3-N/finisher (Table 16). Costs of this technology are from the background spreadsheet[8] to the report by DCA (2016) and calculated to 2017-DKK while the technology lifetime (15 years) is from MST (2011k) The yearly costs include sulphuric acid and maintenance among other things. Together, the higher ammonia as well as sulphur content in the manure represent a fertilizer value for the farmer. The sulphur content represents a saving of 15 kg S/ha with a value of 2.5 DKK/kg (Kai, 2017). Note that the ammonia reduction/animal is calculated as 0.25 kg N/finisher compared to 0.39 kg/finisher in DCA (2016) as they include emissions during application.

Table 16. Summary of stable acidification costs for different farm sizes with 33 per cent drained/67 per cent slattered flooring, 2017-DKK

Stable acidification	Unit	75	150	250	500	750	950	185[2]
Ammonia reduction	%	64 %	64 %	64 %	64 %	64 %	64 %	64 %
Ammonia reduction[1]	kg NH_3-N/animal	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Ammonia reduction[1]	Kg NH_3-N/farm/year	737	1,474	2,457	4,914	7,371	9,337	1,818
Investment costs	DKK/farm/year	93,858	102,559	112,627	123,157	131,375	141,964	104,916
O&M	DKK/farm/year	43,767	72,730	112,504	207,725	304,492	380,715	86,477
Costs	DKK/farm/year	137,624	175,288	225,131	330,882	435,867	522,680	191,393
Fertilizer value	DKK/farm/year	4,401	8,801	14,669	29,338	44,006	55,741	10,855
Net costs[1] incl. N value	DKK/farm/year	133,224	166,487	210,462	301,544	391,860	466,939	180,538
Net costs/finisher	DKK/finisher/year	46	28	22	15	13	13	25
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	181	113	86	61	53	50	99

1. With no other technology.
2. The case farm can only install stable acidification in new stable building. The assumed costs for the case farm (185 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (2011k)

Solid cover on manure tanks

The costs of installing a solid cover on manure tanks are based on the background spreadsheet for the report by DCA (2016), while the lifetime of the investment (20 years) is from MST (n.d.b) and is shown in Table 17. Installing a solid cover on manure tanks is feasible on both new and existing tanks. The cover reduces ammonia emissions per animal by 0.03 kg NH_3-N, corresponding to a 50 per cent reduction of the slurry tank emissions, while it is 7 per cent of reductions from the total emission from the animals (see Table 13). Emptying an existing tank, however, will entail additional costs (DCA, 2016). O&M costs include, among other things, savings

[8] Peter Kai, Aarhus University, personal communication August 2017

caused by a reduced amount of rainwater in the tank. The costs are between 1-2 DKK/finisher or 19-78 DKK/reduced kg NH_3-N. The reduction in labour cost as no log book has to be kept is not included in the calculation.

Table 17. Summary of costs of installing solid manure tank cover for different farm sizes, 2017-DKK

Solid manure tank cover	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction[1]	%	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
Ammonia reduction[1]	kg NH_3-N/animal	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Ammonia reduction	Kg NH_3-N/farm/year	75	150	250	500	750	950	370	185
Investment costs	DKK/farm/year	8,703	11,652	21,331	36,931	52,475	66,113	29,450	15,078
O&M	DKK/farm/year	-2,399	-6,362	-10,081	-21,727	-33,372	-42,376	-15,037	-7,872
Costs	DKK/farm/year	6,304	5,291	11,250	15,205	19,103	23,737	14,413	7,206
Fertilizer value[1]	DKK/farm/year	448	896	1,493	2,985	4,478	5,672	2,209	1,104
Net costs[1]	DKK/farm/year	5,856	4,395	9,757	12,220	14,626	18,066	11,741	6,321
Net costs/finisher	DKK/finisher/year	2.0	0.8	1.0	0.6	0.5	0.5	0.8	0.9
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	78	29	39	24	20	19	32	34

1. With no other technology. The effect is 50 per cent reduction of ammonia at the manure tank, not in the stable.
2. The case farm can install solid cover for the entire farm's manure tank capacity. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Source: Peter Kai, Aarhus University, personal communication August 2017; MST (n.d.b)

Cooling

Cooling is assumed only to be relevant to install in the new stable i.e. for 185 AU. Costs of this technology are from the background spreadsheet for the report by DCA (2016) and calculated to 2017-DKK, although the lifetime of the investment (20 years) is from the Environmental Protection Agency's background economic calculations for the cooling technology sheet (MST, 2011l). Installing higher cooling effects requires a larger investment and O&M costs, but also entails larger savings on heat as well as N fertilizer. The calculations are shown for 20 W/m2 in a stable with 25-49 per cent solid floors only (see Appendix for costs for other cooling effects). It is assumed that cooling is only installed in combination with 25-49 per cent flooring and that the heat can be reused in other stables or buildings on the finisher farm. Only the costs for the cooling system and its resulting emission reductions are presented below as additional emission reductions and costs, where the farmer already has installed 25-49 per cent solid floor, and therefore cannot be interpreted on its own. Emission reductions as well as costs for flooring (25-49 per cent) and cooling should thus be added to achieve the net reduction and the costs for low emission floors in combination with cooling.

The emission reduction has been calculated by use of the levels showed in Table 13. In this case however, the reference emission for a finisher is not 0.39 kg NH_3-N but 0.32 kg NH_3-N since it should be taken into account that 25-49 per cent solid flooring reduces 17 per cent of emissions. With a cooling effect of 20 W/m^2, the ammonia emission reduction has been calculated as an additional 0.06 kg NH_3-N/finisher (18.4 per cent) on top of the emission reduction from the low emission floor. For the case farm, the reduction is 226 kg NH_3-N (0.03 kg NH_3-N/animal * 7,215 animals). These reductions should be added to the reductions achieved by installing 25-49 per cent solid floors in order to have the full picture of emission reductions. The costs of cooling include installation, electricity, and maintenance. On the other hand, the farm reuses the heat from the heat pump thus saving on heating in other buildings. Because of the assumed reuse of heat on the farm, net costs are negative thus representing a saving for the farm. These savings have been calculated as 6-10 DKK/finisher and 103-159 DKK/kg reduced kg NH_3-N with larger savings on larger farms. These costs do not include the installation of 25-49 per cent solid floors.

In case the heat cannot be reused, the calculations show costs of 10-15 DKK/finisher or 165-241 DKK/kg NH_3-N. The costs for farms that can only use the heat partly is expected to be in between these two estimates.

Table 18. Summary of cooling costs for different farm sizes and cooling effect of 20 W/m^2 and no reuse of heat, 2017-DKK

Cooling, 20 W/m2, 25-49 % solid floor	Unit	75	150	250	500	750	950	185[2]
Ammonia reduction[1]	%	18.4 %	18.4 %	18.4 %	18.4 %	18.4 %	18.4 %	18.4 %
Ammonia reduction[1]	kg NH_3-N/animal	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Ammonia reduction	Kg NH_3/farm/year	176	352	586	1,173	1,759	2,228	434
Investment costs	DKK/farm/year	10,113	14,237	18,728	29,965	37,474	41,205	15,709
O&M	DKK/farm/year	28,354	55,002	90,126	175,898	261,670	329,525	67,264
Reuse of heat	DKK/farm/year	-56,284	-112,569	-187,615	-375,229	-562,844	-712,936	-138,835
Costs	DKK/farm/year	-17,817	-43,330	-78,761	-169,367	-263,699	-342,206	-55,862
Fertilizer value[1]	DKK/farm/year	1,050	2,100	3,500	7,001	10,501	13,301	2,590
Net costs[1]	DKK/farm/year	-18,130	-44,693	-81,524	-175,630	-273,463	-354,770	-57,725
Net costs/finisher	DKK/finisher/year	-6	-8	-8	-9	-9	-10	-8
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	-103	-127	-139	-150	-155	-159	-133

1. With 25-49 per cent solid floors.
2. The case farm can only install cooling in a new stable building. The assumed costs for the case farm (185 AU) have been calculated proportionally to the farm size.

Source: Peter Kai, Aarhus University, personal communication August 2017; MST (2011l)

Air cleaning (chemical and biological)

Costs of installing and operating air cleaners are estimated by DCA (2016)[9] and calculated in 2017-DKK prices while the lifetime (10 years) of the technologies are from the Environmental

[9] Backgound spreadsheet: Peter Kai, Aarhus University, personal communication August 2017

Protection Agency’s background descriptions for air cleaners (MST 2011m; 2011n). The costs are for stables with 33 per cent drained/67 per cent slatted flooring. It is assumed that if air cleaning is needed in both stables, economies of scale apply and the calculated costs for a farm of 370 AU are used. The tables below show these costs according to farm size and the calculated costs for the case farm – either the whole case farm of 370 AU or one of the stables of 185 AU. The calculations are carried out with both 100 per cent, 60 per cent and 20 per cent ventilation capacity.

Chemical air cleaning

Installing chemical air cleaning and 100 per cent ventilation capacity entails a reduction in ammonia emissions of 0.35 kg NH_3-N/finisher. The lifetime of the technology is 10 years based on the Environment Agency’s technology sheet (MST, 2011m). Among other things, the O&M costs include costs for sulphuric acid used in the cleaner, and net costs include the value of collected NH_3-N and sulphur, which then can be spread as fertilizer on fields. It is assumed that the amount of NH_3-N that is removed by the technology can be applied as fertilizer with a plant uptake of 75 per cent. The additional sulphur content can save fertilizer corresponding to 15 kg S/ha at a value of 2.5 DKK/kg S (Kai, 2017). Reduction costs have been calculated as between 19-26 DKK/finisher and 55-75 DKK/kg NH_3-N, depending on farm size.

Table 19. Summary of costs of installing chemical air cleaning with a 100 per cent ventilation capacity for different farm sizes, 2017-DKK

Chemical air cleaning 100 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction[1]	%	89 %	89 %	89 %	89 %	89 %	89 %	89 %	89 %
Ammonia reduction[1]	kg NH_3-N/animal	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Ammonia reduction	Kg NH_3/farm/year	1,025	2,050	3,417	6,834	10,251	12,984	5,057	2,528
Investment costs	DKK/farm/year	43,558	72,336	123,511	247,021	370,532	530,869	182,796	90,306
O&M	DKK/farm/year	39,000	62,265	96,532	172,829	251,372	338,888	135,380	74,114
Costs	DKK/farm/year	82,558	134,602	220,042	419,850	621,904	869,757	318,176	164,420
Fertilizer value[2]	DKK/farm/year	6,120	12,239	20,399	40,798	61,196	77,515	30,190	15,095
Net costs[1,2]	DKK/farm/year	76,438	122,362	199,644	379,053	560,707	792,241	287,986	149,325
Net costs/finisher	DKK/finisher/year	26	21	20	19	19	21	20	21
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	75	60	58	55	55	61	57	59

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Source: Kai (2017); MST (2011m)

With a ventilation capacity of 60 per cent, air cleaning is less costly, also per reduced kg NH_3-N except for 75 AU. The effect on ammonia emissions have been calculated as in the previous section where the effect is 88 per cent of the effect seen in Table 13 above. With this capacity, ammonia emissions are reduced by 0.31 kg NH_3-N/finisher depending on farm size. As above, it is assumed that the amount of NH_3-N that is removed by the technology can be applied as fertilizer (although with a plant uptake of 75 per cent), which together with the sulphur represents a fertilizer value. Reduction costs have been calculated to be between 12-24 DKK/finisher or 40-77 DKK/reduced kg NH_3-N.

Table 20. Summary of costs of installing chemical air cleaning with a 60 per cent ventilation capacity for different farm sizes, 2017-DKK

Chemical air cleaning 60 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction	%	78 %	78 %	78 %	78 %	78 %	78 %	78 %	78 %
Ammonia reduction[1]	kg NH_3-N/animal	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Ammonia reduction	Kg NH_3/farm/year	898	1,797	2,995	5,989	8,984	11,379	4,432	2,216
Investment costs	DKK/farm/year	40,207	65,653	72,330	144,660	216,991	325,295	107,049	67,248
O&M	DKK/farm/year	34,507	51,031	77,097	138,457	195,320	253,491	108,281	59,995
Costs	DKK/farm/year	74,714	116,683	149,427	283,117	412,310	578,786	215,330	127,243
Fertilizer value[2]	DKK/farm/year	5,363	10,727	17,878	35,755	53,633	67,935	26,459	13,229
Net costs[1,2]	DKK/farm/year	69,350	105,957	131,550	247,362	358,678	510,851	188,871	114,013
Net costs/finisher	DKK/finisher/year	24	18	13	13	12	14	13	16
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	77	59	44	41	40	45	43	51

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Source: Peter Kai, Aarhus University, personal communication August 2017; MST (2011m)

With a still smaller ventilation capacity at 20 per cent, the technology's costs are further reduced. The effect on ammonia emissions have been calculated as in the previous section. In this case, the technology reduces ammonia emissions by 0.27 kg NH_3-N/finisher. As above, it is assumed that the technology entails savings on N and S fertilizer. The calculated reduction costs are between 5-18 DKK/reduced kg NH_3-N or 23-84 DKK/kg NH_3-N, depending on farm size.

As seen from Tables 19-21, the costs per finisher and the costs per kg NH3-N is lower when only 20 per cent ventilation is used. There is only limited economics of scale when the farm has more than 250 AU.

Table 21. Summary of costs of installing chemical air cleaning with a 20 per cent ventilation capacity for different farm sizes, 2017-DKK

Chemical air cleaning 20 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction	%	54 %	54 %	54 %	54 %	54 %	54 %	54 %	54 %
Ammonia reduction[1]	kg NH_3-N/animal	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Ammonia reduction	Kg NH_3/farm/year	622	1,244	2,073	4,146	6,219	7,878	3,068	1,534
Investment costs	DKK/farm/year	27,931	40,216	40,197	65,646	92,256	104,576	54,035	39,673
O&M	DKK/farm/year	28,240	36,248	48,218	76,199	97,438	120,969	63,875	40,194
Costs	DKK/farm/year	56,171	76,465	88,415	141,845	189,694	225,545	117,910	79,867
Fertilizer value[2]	DKK/farm/year	3,713	7,426	12,377	24,754	37,130	47,032	18,318	9,159
Net costs[1,2]	DKK/farm/year	52,458	69,039	76,039	117,091	152,564	178,513	99,592	70,708
Net costs/finisher	DKK/finisher/year	18	12	8	6	5	5	7	10
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	84	56	37	28	25	23	32	46

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (2011m)

Biological air cleaning

Table 22 outlines the costs of the biological air cleaning technology combined with 100, 60 or 20 per cent ventilation capacity, respectively, based on costs by DCA (2016)[10] while the lifetime of the technology (10 years) is from MST (2011n). It is assumed that 50 per cent of the reduced ammonia can be used as fertilizer on fields (MST 2011h). The investments costs are higher than for chemical cleaning and the operational costs are higher and so the total annual costs are also higher. Even though the effect is higher, the costs per NH3-N is higher than for chemical cleaning.

With a 100 per cent ventilation capacity, the calculated reduction by using biological air cleaning is 0.35 kg NH_3-N/finisher. It is assumed that the amount of ammonia saved can be applied as fertilizer (50 per cent plant uptake). Reduction costs have been calculated to be between 20-29 DKK/finisher or 56-84 DKK/reduced kg NH_3-N, depending on farm size.

With a ventilation capacity of 60 per cent, air cleaning is less costly per finisher, but also per kg NH_3-N. The effect on ammonia emissions has been calculated as in the previous section and relative to the effect of 100 per cent capacity, and the result is a reduction of 0.32 kg NH_3-N/finisher. It is assumed that the amount of ammonia saved can be applied as fertilizer (50 per

[10] Background spreadsheet: Peter Kai, Aarhus University, personal communication August 2017

cent plant uptake). Reduction costs have been calculated as between 14-23 DKK/finisher or 44-71 DKK/reduced kg NH_3-N, depending on farm size.

Table 22. Summary of costs of installing biological air cleaning with a 100 per cent ventilation capacity for different farm sizes, 2017-DKK

Biological air cleaning 100 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction	%	88 %	88 %	88 %	88 %	88 %	88 %	88 %	88 %
Ammonia reduction[1]	kg NH_3-N/animal	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Ammonia reduction[1]	Kg NH_3/farm/year	1,014	2,027	3,378	6,757	10,135	12,838	5,000	2,500
Investment costs	DKK/farm/year	46,213	67,968	90,562	180,873	271,403	344,254	133,939	75,422
O&M	DKK/farm/year	42,558	70,682	119,687	225,061	341,696	430,220	171,841	87,871
Costs	DKK/farm/year	88,771	138,650	210,249	405,933	613,099	774,474	305,779	163,293
Fertilizer value	DKK/farm/year	4,034	8,068	13,446	26,893	40,339	51,096	19,901	9,950
Net costs	DKK/farm/year	84,737	130,582	196,802	379,041	572,760	723,378	285,879	153,343
Net costs/finisher	DKK/finisher/year	29	22	20	19	20	20	20	21
Net costs/reduced kg NH_3-N	DKK/kg NH_3-N	84	64	58	56	57	56	57	61

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (2011h); MST (2011n)

Table 23. Summary of costs of installing biological air cleaning with a 60 per cent ventilation capacity for different farm sizes, 2017-DKK

Biological air cleaning 60 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction	%	82 %	82 %	82 %	82 %	82 %	82 %	82 %	82 %
Ammonia reduction[1]	kg NH_3-N/animal	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Ammonia reduction[1]	Kg NH_3/farm/year	944	1,889	3,148	6,296	9,444	11,963	4,659	2,330
Investment costs	DKK/farm/year	38,399	50,816	67,968	135,686	203,623	258,399	100,500	56,485
O&M	DKK/farm/year	32,574	55,636	92,859	172,166	252,808	311,059	132,418	68,667
Costs	DKK/farm/year	70,974	106,452	160,828	307,852	456,431	569,458	232,918	125,152
Fertilizer value	DKK/farm/year	3,759	7,518	12,530	25,059	37,589	47,612	18,544	9,272
Net costs	DKK/farm/year	67,215	98,935	148,298	282,793	418,842	521,846	214,374	115,880
Net costs/finisher	DKK/finisher/year	23	17	15	15	14	14	15	16
Net costs/reduced kg NH_3-N	DKK/kg NH_3-N	71	52	47	45	44	44	46	50

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (2011h); MST (2011n)

With a 20 per cent ventilation capacity, the unit reduction costs (per finisher and per kg NH_3-N) are further reduced. The effect on ammonia emissions has been calculated as in the previous section and the result is a reduction of 0.26 kg NH_3-N/finisher. It is assumed that the amount of ammonia saved can be applied as fertilizer is 50 per cent in this case based on the information in the technology sheet. Reduction costs have been calculated as between 8-19 DKK/finisher or 29-71 DKK/kg NH_3-N, depending on farm size.

Table 24. Summary of costs of installing biological air cleaning with a 20 per cent ventilation capacity for different farm sizes, 2017-DKK

Biological air cleaning 20 %	Unit	75	150	250	500	750	950	370[2]	185[2]
Ammonia reduction	%	67 %	67 %	67 %	67 %	67 %	67 %	67 %	67 %
Ammonia reduction[1]	kg NH_3-N/animal	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Ammonia reduction[1]	Kg NH_3/farm/year	772	1,543	2,572	5,145	7,717	9,775	3,807	1,903
Investment costs	DKK/farm/year	27,573	34,060	38,220	76,190	114,379	145,357	56,473	35,145
O&M	DKK/farm/year	30,365	38,572	49,518	93,123	137,293	175,995	71,099	42,108
Costs	DKK/farm/year	57,938	72,632	87,739	169,313	251,672	321,352	127,573	77,253
Fertilizer value	DKK/farm/year	3,071	6,143	10,238	20,475	30,713	38,903	15,152	7,576
Net costs	DKK/farm/year	54,867	66,489	77,501	148,838	220,959	282,449	112,421	69,677
Net costs/finisher	DKK/finisher/year	19	11	8	8	8	8	8	10
Net costs/reduced kg NH_3-N	DKK/kg NH_3-N	71	43	30	29	29	29	30	37

1. With no other technology.
2. The case farm can install air cleaning for either the whole farm or one of the stables. The assumed costs for the case farm (370 or 185 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; DCA (2016); MST (2011h); MST (2011n)

4.2.2. Cost of technologies for farms with dairy cows

Solid cover on manure tanks

Table 25 below shows the costs of installing solid cover on manure tanks on dairy farms, based on cost data from DCA (2016) and calculated to 2017-DKK (Kai, 2017) whereas the lifetime (10 years) of the technology is from MST (n.d.-b). O&M costs also include maintenance, additional costs for manure application, while savings also include savings on rainwater but not on establishing a surface crust, since this normally does not entail additional costs. With an ammonia reduction of 7 per cent, the reduction is 0.8 kg/dairy cow. The net costs have been calculated to between 74-153 DKK/dairy cow and 95-195 DKK/reduced kg NH_3-N depending on the farm size, where a larger farm size entails lower per unit costs. The time no longer needed for entering observations into a log book has not been included.

Table 25. Summary of costs of a solid cover on manure tanks for different farm sizes with cubicles and split floor and channels, 2017-DKK

Solid cover on manure tank	Unit	75	150	250	500	750	950	320[2]	160[2]
Ammonia reduction[1]	%	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
Ammonia reduction[1]	kg NH_3-N/dairy cow	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Ammonia reduction	Kg NH_3/farm/year	44	88	147	294	441	559	188	94
Investment costs	DKK/farm/year	8,888	12,023	21,956	38,158	54,361	68,473	26,263	13,438
O&M incl. savings on rainwater	DKK/farm/year	-37	-1,639	-2,210	-5,984	-9,758	-12,464	-3,329	-1,581
Costs	DKK/farm/year	8,851	10,384	19,746	32,174	44,603	56,009	22,933	11,857
Fertilizer value[1]	DKK/farm/year	246	492	820	1,639	2,459	3,115	1,049	525
Net costs[1]	DKK/farm/year	8,605	9,892	18,926	30,535	42,143	52,894	21,884	11,332
Net costs/dairy cow	DKK/dairy cow/year	153	88	101	81	75	74	91	94
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	195	112	129	104	95	95	116	120

1. With no other technology.
2. The case farm can install solid manure tank cover for either the whole farm or one of the stables. The assumed costs for the case farm (320 or 160 AU) have been calculated proportionally to the farm size.

Source: Peter Kai, Aarhus University, personal communication August 2017; MST (n.d.-b)

Acidification

The costs of stable acidification in dairy barns are shown in Table 26 below. As opposed to finisher farms, it is assumed that stable acidification can also be installed in the old stable. The ammonia reduction is, as seen above, 50 per cent and calculated as 5.6 kg NH_3-N/dairy cow. Costs of this technology are from background calculations[11] from DCA (2016) and calculated to 2017-DKK, while the technology's lifetime (15 years) is from MST (2011o). As for finishers, the O&M costs include maintenance and sulphuric acid among other things. On this background, the costs have been calculated to between 274-1,459 DKK/dairy cow and 49-260 DKK/reduced kg NH_3-N depending on farm size, where the costs per unit decreases with farm size. It should be noted that the emission reduction is calculated as 50 per cent of the total emissions from a dairy cow, and thus does not entail any emission reduction from the field, leading to an underestimation of the achieved reductions and overestimation of the net costs including the fertilizer value.

Table 26. Summary of stable acidification costs for different farm sizes with cubicles and split floor and channels, 2017-DKK

Stable acidification	Unit	75	150	250	500	750	950	320[2]	160[2]
Ammonia reduction[1]	%	50 %	50 %	50 %	50 %	50 %	50 %	50 %	50 %
Ammonia reduction[1]	kg NH_3-N/dairy cow	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Ammonia reduction	Kg NH_3/farm/year	315	630	1,051	2,102	3,152	3,993	1,345	673
Investment costs	DKK/farm/year	59,518	59,518	59,518	65,104	65,104	65,104	65,104	59,518
O&M	DKK/farm/year	27,589	41,787	60,437	109,501	156,529	194,135	73,720	41,626
Costs	DKK/farm/year	87,107	101,305	119,955	174,605	221,633	259,239	138,824	101,144
Fertilizer value[1] (N and S)	DKK/farm/year	5,065	10,131	16,884	33,769	50,653	64,161	21,612	10,806
Net costs[1]	DKK/farm/year	82,042	91,174	103,071	140,836	170,980	195,078	117,212	81,609
Net costs/dairy cow	DKK/dairy cow/year	1,459	810	550	376	304	274	463	680
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	260	145	98	67	54	49	83	121

1. With no other technology.
2. The case farm can install acidification on either the whole farm or one of the stables. The assumed costs for the case farm (320 or 160 AU) have been calculated proportionally to the farm size.

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (2011o)

[11] Peter Kai, Aarhus University, personal communication August 2017

Dredgers for dairy barns

Stationary, wire-drawn, dredger

The costs of installing wire-drawn dredgers are based on the cost calculations from the Environment Agency's technology sheets and are estimated for a dairy cow stable where 15 per cent of the cows are non-lactating cows (MST, n.d.c). In the following, however, unit costs per cow and reduced amounts of ammonia are divided with the total number of animals in the barn, including dry cows. The lifetime of the technology is 12.5 years (MST, n.d.c).

O&M costs include electricity consumption for the wire station. Additional investment costs of about 17,000 DKK in 2017-DKK for the wire station are necessary if installing this technology in existing stables (MST, 2010a). Dredging reduces ammonia emissions from the floor by 25 per cent (MST, 2010a,) and thus by 2.8 kg NH_3-N/dairy cow, which as stated above is an over-estimation compared to the whole ammonia effect from stable, tank, and field application. Based on this, the net costs are calculated to between 108-330 DKK/dairy cow (including non-lactating cows) or 39-118 DKK/reduced kg NH_3-N. For the farm of 320 AU, the costs include the additional investment cost for installing the technology in the existing stable. It should be noted that these net costs including the fertilizer value are underestimated since the reduction in ammonia does not take into account any increased emissions from the tank or field.

Table 27. Summary of costs for wire-drawn dredgers on slatted floor for different farm sizes with cubicles and split floor and channels, 2017-DKK

Dredgers on drained floor, wire	Unit	75	150	250	500	750	950	320[2]	160[2]
Ammonia reduction[1]	%	25 %	25 %	25 %	25 %	25 %	25 %	25 %	25 %
Ammonia reduction[1]	kg NH_3-N/dairy cow	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Ammonia reduction	Kg NH_3/farm/year	158	315	525	1,051	1,576	1,996	673	336
Investment costs	DKK/farm/year	9,743	9,837	11,167	22,333	33,500	42,310	15,390	8,820
O&M	DKK/farm/year	9,686	10,215	12,075	24,148	36,222	45,731	15,455	9,312
Costs	DKK/farm/year	19,429	20,052	23,242	46,482	69,722	88,041	30,845	18,132
Fertilizer value[1]	DKK/farm/year	878	1,756	2,927	5,855	8,782	11,124	3,747	1,874
Net costs[1]	DKK/farm/year	18,551	18,295	20,314	40,627	60,940	76,916	27,098	16,258
Net costs/dairy cow	DKK/dairy cow/year	330	163	108	108	108	108	113	135
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	118	58	39	39	39	39	40	48

1. With no other technology.
2. The case farm can install dredgers on either the whole farm or one of the stables. The assumed costs for the case farm (320 or 160 AU) have been calculated proportionally to the farm size.

Sources: MST (n.d.c); MST (2010a)

Robot dredger

Costs of installing robot dredgers are also based on the cost calculations from the Environment Agency's technology sheets and thus apply to a dairy farm where 15 per cent of the dairy cows are not lactating. O&M costs also include electricity consumption as above. The lifetime of the technology is 10 years (MST, n.d.c). Robot dredgers can also be installed in both new and existing stables and no additional cost is needed when installing it in an existing stable (MST, 2010a). Reductions in ammonia emissions are the same as for a wire-drawn dredger and thus 2.8 kg NH_3-N/dairy cow. This calculated effect does not consider any increases in ammonia emissions from the tank or field. On this background, the net costs are calculated to between 64-298 DKK/dairy cow or 23-106 DKK/reduced kg NH_3-N depending on farm size. It should be noted that because of the overestimated ammonia emissions, these net costs including the value of N fertilizer are underestimated.

Table 28. Summary of costs for robotic dredgers on slattered floor for different farm sizes with cubicles and split floor and channels, 2017-DKK

Dredgers on drained floor, robotic	Unit	75	150	250	500	750	950	320	160
Ammonia reduction[1]	%	25 %	25 %	25 %	25 %	25 %	25 %	25 %	25 %
Ammonia reduction[1]	kg NH_3-N/dairy cow	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Ammonia reduction	Kg NH_3/farm/year	158	315	525	1,051	1,576	1,996	673	336
Investment costs	DKK/farm/year	15,487	15,487	15,487	15,487	30,974	30,974	14,867	13,215
O&M	DKK/farm/year	2,156	4,256	7,144	14,282	21,418	27,120	9,142	4,556
Costs	DKK/farm/year	17,643	19,743	22,631	29,769	52,392	58,094	24,010	17,771
Fertilizer value[1]	DKK/farm/year	878	1,756	2,927	5,855	8,782	11,124	3,747	1,874
Net costs[1]	DKK/farm/year	16,765	17,986	19,703	23,914	43,609	46,969	20,263	15,898
Net costs/dairy cow	DKK/dairy cow/year	298	160	105	64	78	66	84	132
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	106	57	38	23	28	24	30	47

1. With no other technology.
2. The case farm can install dredgers on either the whole farm or one of the stables. The assumed costs for the case farm (320 or 160 AU) have been calculated proportionally to the farm size.

Sources: MST (n.d.c); MST (2010a)

Low emission flooring with dredgers

Costs for installing low emission flooring with dredgers are from the Environment Agency's background spreadsheet for solid drained floors as additional investment costs compared to the reference flooring and operational costs (MST, n.d.e). This floor type and practice requires additional investment and operation costs including electricity for the dredgers. In some cases, the investment in dredgers will not led to additional costs, but it depends on the situation. The lifetime of the different components is from 7-25 years. Price differences between the reference stable and low emission stable vary per AU because the reference stable and manure handling systems are different for each stable size in the background calculations (MST, n.d.d). With a 50 per cent ammonia reduction of 11.2 kg NH_3-N/dairy cow, the calculated reduction is 5.8 kg NH_3-N/dairy cow. This is calculated as a total reduction thus not considering any emission changes from the tank or field. Therefore, the net costs including fertilizer value are underestimated. Based on this, the net costs have been calculated to 9-105 DKK/dairy cow/year and 2-19 DKK/reduced kg NH_3-N.

Table 29. Summary of additional costs for different farm sizes of installing solid floors with drainage and dredgers compared to the reference floor, 2017-DKK

Solid split floors w. dredger	Unit	75	150	250	500	750	950	160
Ammonia reduction[1]	**%**	50 %	50 %	50 %	50 %	50 %	50 %	50 %
Ammonia reduction[1]	kg NH_3-N/dairy cow	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Ammonia reduction	Kg NH_3/farm/year	315	630	1,051	2,102	3,152	3,993	673
Additional investment costs	DKK/farm/year	1,180	8,508	18,368	44,096	21,398	38,036	10,415
O&M	DKK/farm/year	1,056	2,112	3,520	7,040	10,561	13,377	2,253
Total costs	DKK/farm/year	2,236	10,621	21,888	51,137	31,959	51,413	12,668
Fertilizer value[1]	DKK/farm/year	1,756	3,513	5,855	11,710	17,565	22,249	3,747
Net costs[1]	DKK/farm/year	480	7,108	16,033	39,427	14,394	29,164	8,921
Net costs/dairy cow	DKK/dairy cow/year	9	63	86	105	26	41	74
Net costs/reduced kg NH_3-N[1]	DKK/kg NH_3-N	2	11	15	19	5	7	13

1. With no other technology.
2. The case farm can install dredgers on either the whole farm or one of the stables. The assumed costs for the case farm (320 or 160 AU) have been calculated proportionally to the farm size.

Sources: MST (n.d.d); MST (n.d.e)

4.3 Overview of Cost of Technologies for Finishers and Dairy Cows

Overall, there are a number of technologies available to the farmers in order to reduce ammonia emissions. The cheapest options (often feeding) are seldom an option. The reductions possible for farms with finishers are from 7 to 88 per cent and the costs range from -8 to 25 DKK, taking into account that reuse of heat when cooling slurry is an economic advantage. The costs per kg NH_3-N range from -133 to 99 DKK.

Table 30. Overview of technologies and additional costs for farm with finishers with 185 AU (size of case farm)

Technology	Reduction (%)	Costs per finisher (DKK/finisher)	Cost per NH_3-N (DKK/kg NH_3-N)
25-49 % solid floors	17	4	60
50-75 % solid floors	34	6	43
Stable acidification	64	25	99
Cover of manure tank[1]	7	0.9	34
Cooling (20 W/m^2) [2]	18	-8	-133
Chemical air cleaning (100 %)	89	21	59
Chemical air cleaning (60 %)	78	16	51
Chemical air cleaning (20 %)	54	10	46
Biological air cleaning (100 %)	88	21	61
Biological air cleaning (60 %)	82	16	50
Biological air cleaning (20 %)	67	10	37

Note: Conversion used: DKK 7.45 = 1 euro.

1. 50 per cent reduction of loss in storage.
2. The heat is reused in this option.

For dairy farms, there are few options, and the reduction level is from 7 to 50 per cent. The cost per cow is from 74 to 680 DKK or 13 to 121 DKK/kg NH_3-N. Acidification has been used on many farms and so it is a surprise that the cost is so high. In some cases, the farms will gain higher yields or avoid more expensive applications in the field, which is not included here.

Table 31. Overview of technologies and additional costs for a dairy farm with 210 dairy cows (160 AU) (size of case farm)

Technology	Reduction (%)	Costs per cow (DKK/cow)	Cost per NH_3-N (DKK/kg NH_3-N)
Stable acidification	50	680	121
Cover of manure tank[1]	7	94	120
Wire drawn dredger	25	135	48
Robot dredger	25	132	47
Low emission floor	50	74	13

Note: Conversion used: DKK 7.45 = 1 euro.

1. 50 per cent reduction of loss in storage

5. Emission Requirements and Costs for Case Farms

5.1. The Allowed Emission on Case Farms

The calculation of additional costs for the case farms are based on calculations of the required emission reductions. The calculations consider the case of a 100 per cent expansion in production for the case farms holding finishers, sows, dairy cows, and slaughter chickens (broilers) respectively. The cost calculations are based on a farm situated at a distance of 400 and 2,000 metres, respectively, from ammonia sensitive nature (category 1-3). As shown before, the allowed ammonia emission will be higher, the further away from the Natura 2000 area. The calculations will include 0-2 neighbouring livestock farms, which will also have an impact on the ammonia abatement requirement as described earlier. The focus in this section is on the required emission reductions in different situations, whereas the focus in the subsequent section is on the choice of technology and the costs. The focus in the calculations are on the case farms 400 metres from nature sites as there are less demanding requirements for farms 2,000 metres from nature sites.

Table 32 shows the reduction requirements for the case farms in the case of an expansion of 100 per cent of their production when situated 400 metres from category 1-3 nature. Reading the table downwards, the type of case farm is illustrated together with its basic emissions with no further technology requirements versus emissions with BAT requirements. Reading the table towards the right, the allowed ammonia emission from the farm is shown for each nature type (category 1-3) and whether the number of neighbours affects the allowed emission level. Not all nature types or the number of neighbours are relevant for all situations for the case farms. Nature types 2 and 3 near finisher farms are relevant for these farms' ammonia emission restrictions, though the number of neighbours in these cases do not affect the allowed emissions. When the farm is situated 2,000 metres from a nature area, the allowed emissions are the same as in the baseline and are not affected by the number of neighbours, thus this situation is not included in the table below.

The calculations of the allowed emissions are carried out by the Environmental Protection Agency using the computer program provided by the Agency located on "husdyrgodkendelse.dk" (see also mst.dk/husdyrvejledning).[12]

In this case, a farm with 7,215 finishers (1,945 pig units) 400 metres from a nature area (category 1-3) applies for a permit to expand its operations with 100 per cent to 7,215+7,215 produced finishers (from 1,945 to 3,890 pig units in the building). The basic emission for this farm, before introduction of new technologies, has been calculated by the Environmental Protection Agency to 5,682 kg NH_3-N/year in the case where no nature is in the vicinity of the farm. In the application for a permit, however, the farm reports its emissions with one or more BAT technologies installed and should arrive at 5,040 kg NH_3-N in yearly emissions, as calculated by the Environmental Protection Agency, in order to get a permit to expand the livestock production (see also Table 8, where the case farm is in the 75-210 AU section). The allowed BAT emission level of 5,040 is equal to 0.35 kg NH_3-N/finisher.

If the farm is situated near category 1 nature, i.e. a habitat type inside a Natura 2000 area, and has no neighbours, the farm must install enough technology to reduce emissions even further, to 2,989 kg NH_3-N/year, corresponding to a 47 per cent emissions reduction from the baseline without BAT and 40 per cent compared to the baseline with BAT. If the farm has one neighbour, the farm must install technology reducing emissions by 71 per cent to 1,642 kg NH_3-N compared to the baseline without BAT.

[12] Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017.

In case of an expansion near category 2 and 3 nature, the allowed emission level is 4,066 kg NH_3-N and 6,907 kg NH_3-N, respectively. The reduction required is 28 per cent for category 2 while no reduction is needed for the case farm situated near category 3 nature compared to the baseline scenario when the distance is 400 metres.

The results for dairy cows and broilers follow the same pattern, although the allowed level of ammonia emissions for dairy farms with no neighbours near category 1 nature is higher than the baseline requirement and so there will be no additional requirements due to the production's proximity to category 1 nature.

The calculations also show that farms situated 2,000 metres from nature sites (category 1-3) do not have additional requirements compared to the BAT requirements and so the additional costs of being situated 2,000 metres from category 1-3 nature sites are estimated to zero for the case farms.

Table 32. Allowed ammonia emissions per year from case farms 400 metres from nature areas depending on neighbouring livestock farms, kg NH_3-N/year

Farm type (after expansion)	Baseline emission, before/ after BAT[2)]	No. of neighbours / Nature type	0	1	> 1
14,430 produced finishers	Base = 5,682 kg 0.39 kg/animal BAT = 5,040 kg 0.35 kg/animal -11 %[1)]	Category 1	2,989 kg 0.21 kg/animal -47 %	1,642 kg 0,11 kg/animal -71 %	835 kg 0,06 kg/animal -85 %
		Category 2	4,066 kg 0.28 kg/animal -28 %	-	-
		Category 3	6,907 kg [3)] 0.48 kg/animal 0 %	-	-
120+120 dairy cows with heifers	3,283 kg 13.7 kg/animal /2,585 kg 10.8 kg/animal -21 %	Category 1	2,809 kg [3)] 11.7 kg/animal -14 %	1,592 kg 6.6 kg/animal -51 %	1,052 kg 4.4 kg/animal -68 %
		Category 2	-	-	-
		Category 3	-	-	-
120+120 dairy cows without heifers	Baseline: 2,690 kg N/year (11.2 kg/animal) With BAT: 2,053 kg N/year (8.55) Reduction -24 %	Category 1	2,809 kg[3)] 0 %	1,592 kg -41 %	1,052 kg -61 %
		Category 2	-	-	-
		Category 3	-	-	-
600,000 broilers	3,838 kg 6.4 kg/1,000 animals /3,325 kg 5.5 kg/1,000 animals 13 %	Category 1	2,903 kg 4.8 kg/1,000 animals -24 %	1,967 kg 3.3 kg/1,000 animals -49 %	983 kg 1.6 kg/1,000 animals -74 %
		Category 2	-	-	-
		Category 3	-	-	-

1) Compared to baseline before BAT.
2) BAT is here based on the allowed BAT emissions set by the Environmental Protection Agency.
3) In this case the allowed emission is higher than the BAT requirement.
Note: Allowed emissions 2,000 metres from Natura 2000 are the same as the baseline with BAT requirements.
Source: Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017

The requirements for finishers located 400 metres from nature areas are shown in Figure 3. The BAT requirement of 0.35 kg NH_3-N equals index 100. It is clear that the emission for the same type of stable has been reduced from 2005/06 until now. It should also be noted that the requirements for category 1 with one or more livestock farms require a larger reduction as the emission levels are under 60 per cent of the BAT emission level. In that case, the total emissions will be lower than the initial emission from the farm before the expansion and so the expansion will lead to lower overall emissions if they are carried out.

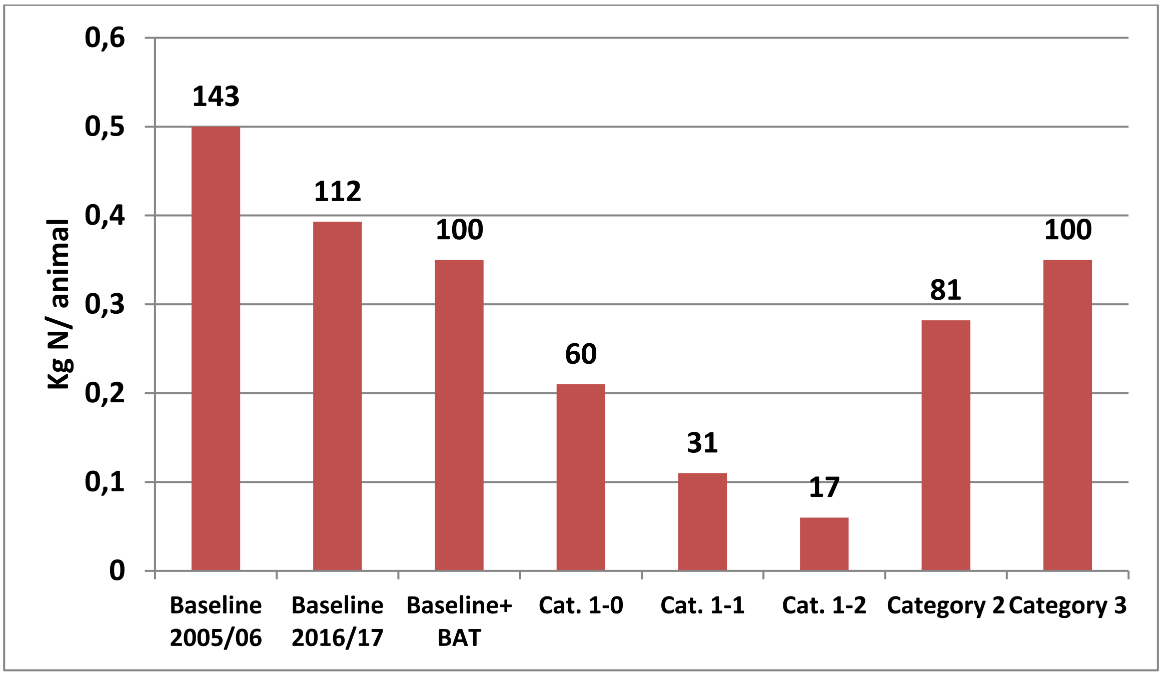

Figure 3. Allowed emission per animal for a farm with 7,215 finishers located 400 metres from different categories of nature and number of neighbours (reference technology is 1/3 drained floor, 2/3 slatted floor)

Index 100 = Baseline + BAT = general ammonia regulation requirement = 0.35 kg NH3-N/animal.
Note: Category 1-0 show the allowed emission near category 1 nature with 0 livestock neighbours. Category 1-1 and 1-2 are with one and two livestock neighbours.
Baseline + BAT include the required BAT level for this farm.
Source: Ditte Eskjær, The Danish Environmental Protection Agency, personal communication, September 2017; and own calculations

As mentioned above, the case farms outlined in the table above form the basis for the analysis of additional costs to farmers of additional ammonia regulation related to sensitive nature (category 1-3) in Denmark. For each case farm, the baseline situation and its costs are calculated for the BAT technologies, where the most cost-effective technologies are chosen and combined to obtain the allowed BAT ammonia emission level as shown in the second column above.

The next step is to compare this with the farm's costs in the situations where the farm is located in the vicinity of nature and neighbouring livestock farms (category 1-3). Again, the most cost-effective ammonia reducing technologies for the required emission level are chosen. Comparisons are made for farms situated 400 and 2,000 metres, respectively, from nature sites (category 1-3). For a farm that is situated 2,000 metres from a nature area (category 1-3), the maximum emissions equal the BAT emissions as shown in the table above and so no additional costs are calculated.

5.2. Cost of the Selected Technologies to Reduce Ammonia Emission on Case Farms

5.2.1. Finishers

Having described the costs of different ammonia reducing technologies, the following will provide the compliance costs for the case farm of achieving the required reductions as shown in section 4.1. As mentioned before, there are limitations related to the stable, which is already on the farm. Establishing a new production with 14,400 finishers would give more flexibility and would lower the costs, but this is not the starting point in this case.

Table 33 shows the allowed emission levels, technology choices, and their costs required for the reference BAT baseline, and the different nature types on the finisher case farm. The table also shows the emissions based on the selected technology. The costs are shown as net costs of the technology on its own and the additional costs of being close to ammonia-sensitive nature. The additional costs of complying with nature-specific ammonia requirements are calculated as the costs of the specific technology necessary in each case minus the costs of the baseline technology, which in this case is the installation of 50-75 per cent solid floors in the new stable to comply with BAT standards. Another option would have been to combine changes in feeding and storage to reduce the emissions by 11 per cent and then use this as the baseline.

As seen in Table 33, the case farm emits 5,682 kg NH_3-N, i.e. 0.39 kg NH_3-N/finisher at the outset. For the farm to adhere to the general BAT requirements, it needs to reduce emissions to 5,040 kg, corresponding to an 11 per cent reduction. To achieve this, the farm can install low emission flooring in the new stable housing 7,215 finishers, reducing emissions by 34 per cent in the new stable and 17 per cent in total. The new emission level for the farm is thus 4,716 kg NH_3-N.

The additional yearly costs of the technology are calculated to 41,410 DKK, corresponding to 43 DKK/reduced kg NH_3-N and 2.9 DKK/finisher. Since all farms need to adhere to this type of requirement, these costs and the emission level serve as a baseline for determining additional costs induced by additional requirements for nature protection purposes.

If the case farm is situated 400 metres from a Natura 2000 site (category 1) and has no neighbours, the farm needs to reduce emissions by 47 per cent to 2,989 kg NH_3-N or 0.21 kg NH_3-N/finisher. This can be done by installing 20 per cent chemical air cleaning in both the old and new stable. This will entail yearly net costs of 89,682 DKK/farm and compared to BAT, an additional yearly cost of 48,272 DKK/farm. This corresponds to the cost of the technology being 6.2 DKK/finisher, and a net cost of 3.3 DKK/finisher compared to installing the baseline BAT technology outlined above.

Table 33. Technology choices and their additional costs compared to adhering to BAT for a finisher case farm 400 metres from nature sites (2017-DKK)

Regulation	Unit	Reference	BAT	Natura 2000			Category 2 nature	Category 3 nature
No. of neighbours	no.			0	1	>1		
Reduction requirement	%	0	11 %	47 %	71 %	85 %	28 %	11
Reduction requirement compared to BAT	%		0 %	41 %	67 %	83 %	19 %	0 %
Emission/farm	kg NH_3-N	5,682	5,040	2,989	1,642	835	4,066	6,907
Emissions /animal	kg NH_3-N /animal	0.39	0.35	0.21	0.11	0.06	0.28	0.48
Technology			50-75 % solid floor in new stable	20 % chemical air cleaning on entire farm	60 % chemical air cleaning on entire farm	100 % chemical air cleaning on entire farm	20 % chemical air cleaning in new stable	50-75 % solid floor in new stable
Actual reduction	%		17 %	54 %	78 %	89 %	27 %	17 %
Actual emission /farm	kg NH_3-N		4,716	2,614	1,250	625	4,148	4,716
Actual emission /animal	kg NH_3-N /animal		0.33	0.18	0.09	0.04	0.29	0.33
Net cost of technology	DKK/case farm		41,410	89,682	178,960	278,075	65,753	41,410
Net cost of technology	DKK /reduced kg NH_3-N		43	29	40	55	43	43
Net cost of technology	DKK /finisher		2.9	6.2	12.4	19.3	4.6	2.9
Net cost compared to BAT	DKK/case farm		0	48,272	137,550	236,665	24,343	0
Net cost compared to BAT	DKK /reduced kg NH_3-N		0	23	40	58	43	0
Net cost compared to BAT	DKK /finisher		0	3.3	9.5	16.4	1.7	0

1. Calculated as nature-specific technology cost minus cost of BAT technology cost, i.e. 50-75 per cent solid floors.
2. Calculated as nature-specific technology cost minus cost of BAT technology cost, i.e. 50-75 per cent solid floors divided by emission level with nature-specific technology minus emission level with BAT technology.
3. Calculated as nature-specific technology cost minus cost of BAT technology cost, i.e. 50-75 per cent solid floors divided by 14,430 finishers.

Sources: MST (2009); Peter Kai, Aarhus University, personal communication August 2017; MST (2011m)

When situated close to a Natura 2000 site (category 1) and having one livestock neighbour, the farm needs to reduce emissions further, by 71 per cent down to 1,642 kg NH_3-N or 0.11 kg NH_3-N/finisher. This emission reduction can also be reached by installing a chemical air cleaner, although combined with a higher ventilation capacity of 60 per cent. This entails yearly net costs of 178,960 DKK/farm, and additional costs of 137,550 DKK/farm when comparing to installing the BAT technology. The costs of this technology correspond to 12.4 DKK/finisher and compared to BAT this is an additional cost of 9.5 DKK/finisher.

Having two livestock neighbours or more while being 400 metres from a nature category 1 area, the farmer needs to reduce emission by 85 per cent, down to 835 kg NH_3-N. By installing a higher ventilation capacity (100 per cent) with a chemical air cleaner, emissions can be reduced to 625 kg NH_3-N. This requires a yearly net cost of 278,075 DKK/farm or an additional cost of 236,665 DKK/farm when comparing to the BAT baseline. This corresponds to net costs of the technology 19.3 DKK/finisher and an additional 16.4 DKK/finisher compared to the BAT baseline with 50-75 per cent solid flooring.

Adhering to ammonia reduction requirements when situated nearby category 2 nature entails lower costs. In this case, the farmer can install chemical air cleaning (20 per cent capacity) in the new stable and achieve an overall reduction of 27 per cent for the farm as a whole. The net costs of this technology are calculated to 65,753 DKK/farm/year and when comparing to installing BAT technology, the additional costs are 24,343 DKK/farm/year. Per finisher, the technology costs are 4.6 DKK, which is 1.7 DKK more per finisher than the baseline BAT technology of 50-75 per cent solid flooring.

All in all, the options for the production of finishers indicate that the cost per kg NH_3-N vary from 23 to 58 DKK/kg NH_3-N, and the costs per finisher increases from 1.7 to 16.4 DKK with increasing reduction requirements.

5.2.2. Dairy cows

To adhere to BAT when expanding from 120 to 240 dairy cows, the dairy farm needs to achieve ammonia reductions of 24 per cent compared to the baseline/reference stable of 2,690 kg NH_3-N. This corresponds to a total emission of 2,053 kg NH_3-N. To adhere to this emission level, the chosen technologies entail installing wire-drawn dredgers in both the old and the new stable. Another option would be to install low emission flooring and dredgers in the new stable, which reduces emission by 50 per cent, thus achieving a total reduction of 25 per cent for the entire farm. Dredgers in both stables achieve an emission reduction of 25 per cent and a combined yearly net cost including the value of N fertilizer of 27,098 DKK, 113 DKK/dairy cow or 40 DKK/reduced kg NH_3-N. This emission and cost level serves as a baseline to estimate the additional costs of being close to Natura sites (category 1-3).

If the dairy case farm is situated close to Natura 2000 areas (category 1) and has no neighbours in the proximity, the allowed emission is 2,809 kg NH_3-N. This is higher than the reference without BAT and 37 per cent higher than the BAT level. The explanation is that the allowed emissions are based on a detailed calculation in the program, which in this case allows a larger emission than in the BAT standards.

This means that even if rearing (heifers and calves) is included in the case farm's emission calculation, and more emissions reductions thus need to be achieved from the dairy cows, there is some room to adhere to this when the farm is situated in the proximity to Natura 2000 while having no neighbours. It is assumed, however, that all farms need to adhere to the BAT requirements, and thus it is assumed that the farm situated near Natura 2000 and with no neighbours installs the BAT technology as described above. This means that there are no additional costs for the case farm compared to BAT when in proximity (400 metres) to Natura 2000 while having no neighbours. The farm will thus have the same costs as when adhering to BAT with 27,098 DKK in yearly net costs including the value of N fertilizer.

Being in proximity of category 1 nature and having one neighbour nearby, the farm has to reduce emissions to 1,592 kg NH_3-N, which is 41 per cent compared to the reference situation with no technology. The chosen technology to achieve this is to install acidification in both the new and existing stable. This entails yearly net costs of 117,212 DKK/case farm including the value of N fertilizer, which compared to the BAT technology is an additional cost of 90,114 DKK/farm, corresponding to 375 DKK/dairy cow or 134 DKK per additionally reduced kg NH_3-N when going from BAT to this reduction level. A situation where the emission requirement is fulfilled using partly acidification and dredgers might have been slightly cheaper, but it might involve higher costs related to storage, which is not included in the calculation.

Having two or more neighbours while also being in proximity of category 1 nature, the farm needs to reduce ammonia emissions by 61 per cent to 1,052 kg NH_3-N. To achieve this emission level, the chosen technology in the table below is to install stable acidification in both stables and dredgers in the new stable. This enables a reduction of 75 per cent in the new stable as the technologies are additive (50+25 per cent) and a reduction of 50 per cent in the existing stable, and thereby a total reduction of 63 per cent. This entails a net cost including the value of N fertilizer of 133,470 DKK yearly for the case farm, corresponding to 79 DKK/kg NH_3-N reduced or 556 DKK/dairy cow. Compared to BAT, the additional yearly net cost is 106,372 DKK/farm. The additional cost is thus 443 DKK/dairy cow and 105 DKK per additionally reduced kg NH_3-N compared to the BAT technology level. The cost per reduced kg NH_3-N is lower than for one neighbour as it has been decided that the acidification covers both stables.

Table 34. Reduction costs for a dairy case farm located 400 metres from nature sites, 240 dairy cows

Regulation	Unit	Reference	BAT	Natura 2000		
No. of neighbours	no.			0	1	> 1
Reduction requirement	%	0	24	0	41	61
Reduction requirement compared to BAT	%			0	22	49
Emission/farm	kg NH_3-N	2,690	2,053	2,809	1,592	1,052
Emission/animal	kg NH_3/dairy cow	11.2	8.6	11.7	6.6	4.4
Technology			Dredgers in both stables	Dredgers in both stables	Stable acidification in both stables	Stable acidification in both stables + dredgers in new stable
Reduction	%		25	25	50	63
Emission/farm	kg NH_3-N		2,018	2,018	1,345	1,009
Emission/animal	kg NH_3-N /dairy cow		6.30	6.30	4.20	3.15
Net cost of technology	DKK/case farm		27,098	27,098	117,212	133,470
Net cost of technology	DKK /reduced kg NH_3-N		40	40	87	79
Net cost of technology	DKK/dairy cow		113	113	488	556
Net cost compared to BAT	DKK/case farm		0	0	90,114	106,372
Net cost compared to BAT	DKK /reduced kg NH_3-N		0	0	134	105
Net cost compared to BAT	DKK/dairy cow		0	0	375	443

Sources: Peter Kai, Aarhus University, personal communication August 2017; MST (n.d.c; 2010a; 2011o)

5.2.3. Broilers

Heat exchangers for broiler barns

Costs for heat exchangers have been collected directly from the sales company of the technology in Denmark, Rokkedahl Energi. For a farm of 300,000 broilers, one heat exchanger requires investment and installation costs of 426,000 DKK. The estimated lifetime of the technology is 20-30 years. Yearly operation costs have been estimated to 7,000 DKK, which includes a change of filter and cleaning. The heat exchanger uses electricity of 0.06 KWh/broiler, while the stable will use less electricity for standard ventilation.[13] Here, it is assumed that the additional electricity usage corresponds to the amount of electricity saved on existing ventilation. A conservative lifetime of 25 years is used in the following calculation of yearly investment costs. The table below

[13] Jesper Toft, Rokkedahl Energi, personal communication, September 2017.

shows the reductions by using the technology and the associated costs for case farms with 300,000 and 600,000 chickens, respectively.

Table 35. Reduction costs for case farms 400 metres from nature sites, 300,000 and 600,000 broilers, 35 days

Heat exchanger	Unit	300.000 broilers	600.000 broilers
Ammonia reduction[1]	%	30 %	30 %
Ammonia reduction[1]	kg NH_3-N/1,000 broilers	1.9	1.92
Ammonia reduction	kg/farm/year	576	1,151
Additional investment costs	DKK/farm/year	27,269	54,538
O&M	DKK /farm/year	7,000	14,000
Total costs	DKK /farm/year	34,269	68,538
Fertilizer value[1]	DKK /farm/year	2,062	6,874
Net costs[1]	DKK /farm/year	32,207	61,664
Net costs/1,000 broilers	DKK/1,000 broilers/year	54	103
Net costs/reduced kg NH_3-N[1]	DKK /kg NH_3-N	56	54

1. Assuming costs of technology are proportional to number of animals.
Note: Heat exchanger might have other benefits, which might lower total energy costs and improve animal welfare, but they are not included.
Sources: Jesper Toft, Rokkedahl Energi, personal communication, September 2017; ETA-Danmark (n.d.)

Reduction costs for the broiler case farm

For the broiler case farm, the ammonia reducing technology is limited to the heat exchanger. As this reduces ammonia emissions by 30 per cent, the case farms that are in proximity to Natura 2000 at the same time as having one or more neighbours do not have the possibility to expand at this magnitude.

The table below compares the costs of installing heat exchanger technology to achieve larger ammonia reductions to the BAT level, which all farms must adhere to. Installing a heat exchanger in the new stable reduces the farm's emissions by 15 per cent from 3,838 to 3,262 kg NH_3-N and requires a yearly net cost calculated to 32,207 DKK, corresponding to 56 DKK/reduced kg NH_3-N and 54 DKK/1,000 chickens.

To achieve the allowed emission level when the case farm is situated near category 1 sites and does not have neighbours in the proximity, it is necessary to install the heat exchanger in both the new and old stable to achieve a reduction of 24 per cent compared to no technology. The heat exchanger reduces emissions by 30 per cent in both stables. In this case, the farm's total emissions are 2,687 kg NH_3-N. Assuming that costs are proportional to the number of chickens, this entails additional yearly net costs compared to the BAT level of 32,207 DKK, namely 56 DKK/reduced kg NH_3-N above the BAT level, and 54 DKK/1,000 additional chickens.

Beyond this emissions reduction level, and with the current technology list by the Environmental Protection Agency, it will not be feasible to achieve the necessary emissions reductions and thereby be able to expand and double the case farm when it is situated near Natura 2000 areas and has neighbours.

Table 36. Reduction costs for broiler case farm 400 metres from nature sites, 600,000 broilers

Regulation		Refer-ence	BAT	Natura 2000		
No. of neighbours	no.			0	1	>1
Reduction requirement	%	0	13	24	49	74
Emission/farm	kg NH_3	3.838	3.325	2.903	1.967	983
Emissions/animal	kg NH_3/1,000 broilers	6.4	5.5	4.8	3.3	1.6
Technology			Heat exchanger in new stable	Heat exchanger on entire farm		
Reduction	%		15	30	not possible	not possible
Emission/farm	kg NH_3-N		3,262	2,687	not possible	not possible
Emission/animal	kg NH_3-N /1,000 broilers		5.4	4.5	not possible	not possible
Net cost of technology	DKK/case farm		32,207	64,414	not possible	not possible
Net cost of technology	DKK/reduced kg NH_3-N		56	56	not possible	not possible
Net cost of technology	DKK/1,000 broilers		54	107	not possible	not possible
Net cost compared to BAT	DKK/case farm		0	32,207	not possible	not possible
Net cost compared to BAT	DKK/reduced kg NH_3-N		0	56	not possible	not possible
Net cost compared to BAT	DKK/1,000 broilers		0	54	not possible	not possible

Source: Own calculations based on Jesper Toft, Rokkedahl Energi, personal communication, September 2017, ETA-Danmark (n.d.)

5.2.3. Summary for Case Farms

The results from the case farms are summarized in Table 37. The calculations have not included requirements for dairy cows and finishers in relation to category 2 and 3 nature.

The analysis for the three case farms shows that the additional costs of being located near category 1 nature sites are limited as long as there are no livestock neighbours. The farm costs are under 50,000 DKK and the cost per NH_3-N is below or around 50 DKK/kg NH_3-N.

The analysis also shows that the additional costs increase with the number of livestock neighbours. With one livestock neighbour the costs increase by 90-138,000 DKK/year and the cost of reduction increases to around 40-134 DKK/kg additionally reduced NH_3-N compared to BAT. For the broiler farm, no technology is available to reach this required emission level.

For the case where there are two or more livestock neighbours near category 1 nature, the additional costs compared to the chosen BAT technology are around 106,000-237,000 DKK/year or around 60-105 DKK/kg NH_3-N. For the broiler farm, no technology is available to reach this required emission level. The costs are higher for dairy farms than finishers in terms of costs per reduced NH_3-N emissions.

Finally, for the case farm with finishers near category 2 and 3 areas, the costs are lower and a level of 0-24,000 DKK is calculated or 43 DKK/kg NH_3-N. This is around 2 DKK/finisher, which is below the limit of 8 DKK/finisher set as a possible maximum cost level for the livestock regulation.

Table 37. Additional costs for case farms related to ammonia requirements for case farms near category 1-3 nature and compared to BAT emission requirements

Regulation	Natura 2000			Category 2 nature	Category 3 nature
No. of neighbours	0	1	> 1		
Cost per farm					
Finishers	48,272	137,550	236,665	24,343	0
Dairy cows	0	90,114	106,372		
Broilers	32,207	Not possible	Not possible		
Cost per unit					
Finishers	3.3	9.5	16.4	1.7	0
Dairy cows	0	375	443		
Broilers (1,000)	54	Not possible	Not possible		
Cost per kg NH_3-N					
Finishers	23	40	58	43	0
Dairy cows	0	134	105		
Broilers	56	Not possible	Not possible		

Note: Costs per kg NH_3-N are calculated as the additional costs in relation to the additional reduction in ammonia emission (marginal cost approach). There are no calculated values for dairy cows and broilers for category 2-0 and 3-0. Source: Own calculations

One should be careful to make to general conclusions based on a limited number of case farms as they do not represent a larger sample of situations or all types of livestock. The situations will vary between farms and other technologies might have to be used depending on the local conditions.

The results here indicate that farms, intending to expand their farm near category 1 nature where there are no livestock neighbours or where the farm is near category 2 and 3 nature sites, will typically have an additional cost in the range of 0-100,000 DKK/year compared to BAT costs. Often, the cost will not be too high to prevent the expansion intended. The cost for finishers will be lower than the additional cost of around 8 DKK per finisher used in the assessments of the BAT levels as the limit for excessive costs (see table 33) (Jacobsen, 2009). The analysis here indicates that new technology in the stables would be required in most cases, but it could be that some farms are able to fulfil the requirements without this as they use changes in feeding or cover of slurry storage etc.

For investments near category 1 with one or more livestock neighbours, the costs are higher and the technology requirement more complex. The additional costs on top of the BAT technology are from 90-250,000 DKK/year, and in some cases, the costs may be too high for the farmer and therefore the investment will be abandoned. Also, the technology options will have to be combined sometimes, and in some cases, the technology available cannot give the required emission reductions. In some cases, this will make the farmer pursue other options such as locating the expansion on another site or moving the whole farm to a new location.

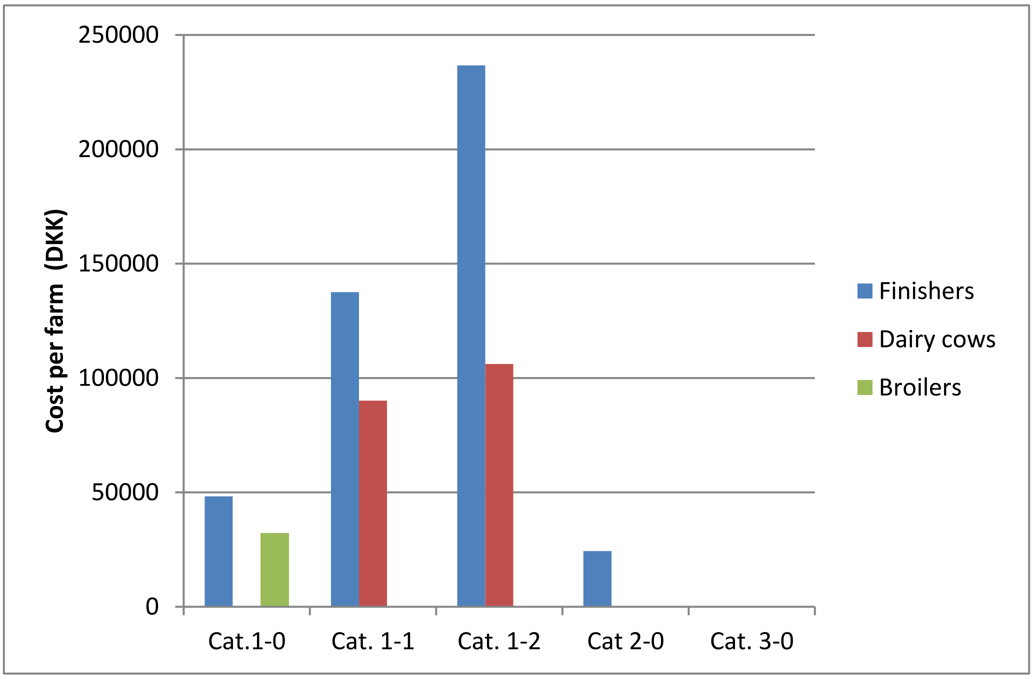

Figure 4. Additional farm costs for farms near category 1-3 nature compared to the BAT emission requirements

Note: There are no calculated values for dairy cows and broilers for category 2-0 and 3-0 as no technologies can meet the reduction requirements. Source: Own calculations

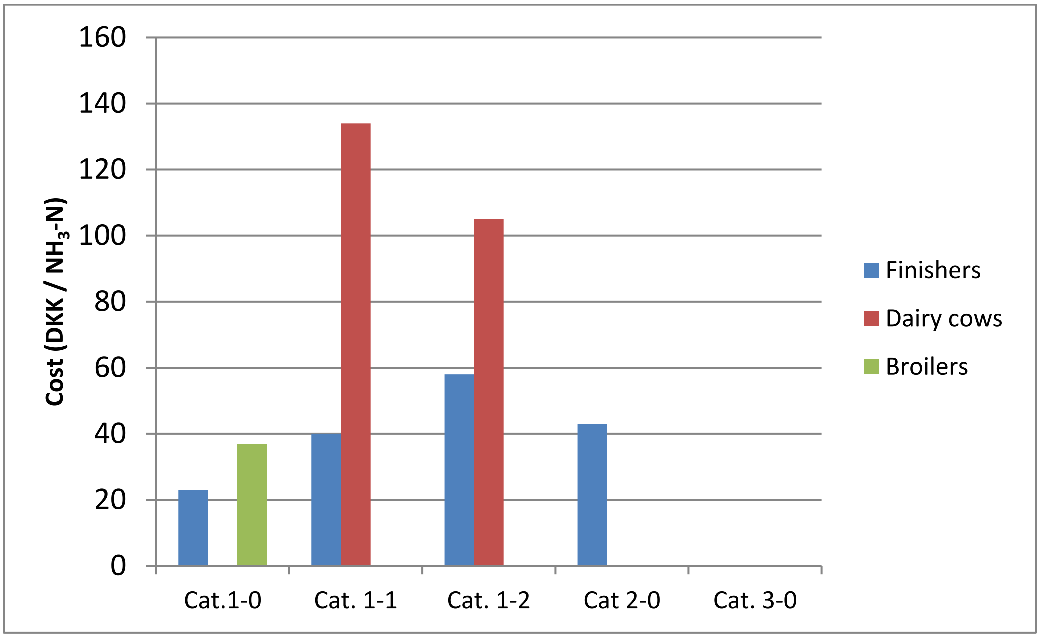

Figure 5. Cost per NH_3-N removed for case farms near category 1-3 nature compared to the BAT emission requirements

Note: There are no calculated values for dairy cows and broilers for category 2-0 and 3-0.
Source: Own calculations

In a national perspective, it is hard to estimate the costs of the regulation based on few case farms, so the estimate gives an order of magnitude, since the number of applicants related to category 1-3 nature every year is very uncertain. As shown earlier, it is estimated that the number of applications related to category 1 nature every year is around 30-40.

A low estimate would be that two-thirds of the applications related to category 1 have no livestock neighbours, whereas the rest are related to category 1 nature with 1 or 2 livestock neighbours. In that case, the total cost for the farms would be around 2.5 million DKK/year (30* 2/3* 50,000 + 30 * 1/3 * 150,000) based on the middle value of the interval stated above. On top of this comes another 40 applications related to category 2 and 3 nature, where minor adjustments are implemented at a total cost per farm of 25,000 DKK/year. The total additional cost is then 3.5 million DKK/year.

A higher estimate would be based on 40 applications where two-thirds are related to category 1 with 1 or more livestock neighbours and one third is related to category 1 with no neighbours. On top of this comes perhaps another 60 applications linked to category 2 and 3 nature, but also requiring some new technology as discussed earlier (see Table 9). In that case, the total costs would be around 9 million DKK/year (40 * 2/3 * 250,000 DKK + 40 * 1/3 * 50,000 + 60 * 25,000).

Altogether this indicates an additional cost related to nature sites of around 4-9 million DKK/year, which is limited compared to the annual costs on livestock farms, but for some farms, it can be a high cost.

5. Conclusion and Discussion

The purpose of this analysis was to estimate the costs for farms that want to increase their livestock farm near Natura 2000 sites (category 1) or other nature sites (category 2 and 3) in Denmark.

The analysis is performed as a budget financial economic analysis. The socioeconomic costs are not calculated and so the costs cannot directly be compared with benefit estimates. The interest used is 4 per cent and the lifespan of the asset is 7-25 years depending on the technology and its components.

The analysis is based in the livestock regulation, which was in place until August 1st, 2017. The calculations are based on three case farms (finishers, dairy cows, and broilers) and the expansion analysed is an increase of the livestock production by 100 per cent. After the expansion, the finisher farm produces 14,430 finishers. The dairy farm has 240 cows and the broiler operation has a production of 600,000 chickens a year. The case farms are located 400 and 2,000 metres away from ammonia sensitive nature respectively.

The sizes of the expansion are probably a little smaller than what is typically found in Denmark today, but it has been coordinated with similar analyses in Germany and the Netherlands using the same sizes of expansion.

The overview of the current livestock in Denmark shows that most livestock farms are located in the western part, whereas the Natura 2000 sites are located across the whole country. Less than 5 per cent of the livestock is situated closer than 500 meters from category 1 nature (Natura 2000), but a majority of all livestock is situated near either category 1,2 or 3 nature. When farms are near category 3 nature types, the municipalities set the requirements based on case individual assessments in relation to the local nature and so in some cases, these farms will have further restrictions. We find that farms near Natura 2000 (< 1,000 metres) have an average size, which is 20 AU (10-15 per cent) smaller than farms more than 1,000 metres away from Natura 2000 sites (category 1-2).

The main livestock operations in Denmark are pig and dairy farms. The overview of the current housing systems show that farms are moving towards lower ammonia emission technologies although only 22 per cent of new applications include new housing technology. Today, most Danish livestock has been through an environmental assessment since the previous regulation was implemented in 2011.

It is assumed that the local authorities will give permits to 320 applications every year of which 30-40 are related to livestock farms near Natura 2000 sites (category 1) as this requires the use of new technology in the buildings. This includes probably around 10 per cent of all livestock involved in applications every year.

The regulatory setup in Denmark is rather complex, but in relation to the expansion of livestock, the general requirements regarding ammonia emissions are linked to the Best Available Technology (BAT) requirements, which all livestock farms have to fulfil. Furthermore, for livestock farms, that want to expand near category 1-3 nature, further restrictions are in place, which will reduce the allowed ammonia emission from the farm after expansion. The requirements are mainly linked to the new part of the production but can also be put on the existing production in some cases. The allowed deposition for farms near category 1 nature is linked to standard national values.

The new regulation from August 1st, 2017, changes the focus from emission per animal to emission per m^2 or place unit. The new regulation is intended to be simpler, include fewer levels, and so the requirement linked to reference technology is no longer included. The overall nature protection level is assumed to be the same as the old regulatory setup and the allowed emission requirements are still lower as the farm size increases.

The ammonia emission requirements for the case farms are calculated by the Environmental Protection Agency using the standard application tool (husdyrgodkendelse.dk). The reduction requirements for nature categories 1-3 vary from 0-85 per cent compared to the reference technology and with 0-83 per cent compared to the BAT requirements. The largest reduction requirements are found for farms near category 1 nature with one or more livestock farms nearby. The calculations for the finisher farm located near category 2 and 3 nature sites are included, although this is not Natura 2000 sites. These calculations are not included for the dairy farm and the farm with broilers. The calculations do not include other requirements linked to smell or noise, just as previous requirements linked to N and P losses are not included.

The report describes a range of technologies available to the farmer in order to meet the emission requirements. The technologies include air scrubbers, cooling, as well as acidification, which is commonly used in Denmark. The challenge is to find the technology or combination of technologies that gives the right effect, since not all technologies work well together or have fully additive effects.

Also, the farms might address the requirements differently. Some farms might find that the required emission reduction for a specific expansion and site is too large and therefore decide to locate the expansion of the business on another one of their farms than the one which is the optimal one. Alternatively, they abandon the expansion or move their farm to another location where there is more room for expansion. These situations and related costs are not included in this analysis.

When trying to estimate the overall costs, it is necessary to estimate how many farms have expanded in each category. As discussed earlier, there are no statistics on the number of farms with the category 1-3 requirement.

The results indicate that farms intending to expand their farm near (400 metres within) category 1 nature, while having no livestock neighbours, or near category 2 or 3 sites, will typically have costs in the range of 0-90,000 DKK/year. Often, the cost will not be too high to prevent the expansion intended based on the cost per unit compared to the intended limit per unit set in the regulation. The analysis indicates that new technology in the stables would be required in most cases, but some farms might be able to fulfil the requirements without this as they use changes in feeding, cover on slurry storage etc.

For investments near category 1 nature with one or more livestock neighbours, the costs are higher and the technology requirement more complex. The costs are from 120-280,000 DKK/year and so in some cases, the costs will be too high for the farmer and the investment will be abandoned. Also, the technology options will sometimes have to be combined and in some cases, the technology available cannot provide the required emission reductions. In some cases, this will make the farmer pursue other options such as locating the expansion on another site or move the whole farm to a new location. For farms, closer than 400 metres to the Natura 2000 sites (category 1), the requirements will be more difficult to achieve.

The analysis shows that there are no additional costs for farms 2,000 metres away from category 1 nature sites and therefore no additional technology has to be implemented.

A low estimate of the total costs would be that two-thirds of the applications relate to category 1 with no livestock neighbours and the rest relates to category 1 with 1 or 2 neighbours. In that case, the total costs for the farms would be around 2.5 million DKK/year. On top of this comes some applications related to category 2 and 3 nature and so the total costs are 3.5 million DKK/year.

A higher estimate would be based on 40 applications, where two-thirds are related to category 1 with 1 or more neighbours, and one-third is related to category 1 with no neighbours. On top of this comes perhaps another 60 applications linked to category 2-3 nature. The total costs are around 9 million DKK/year.

This estimate is based on the case farms and so if the applications in a Danish context are higher, the costs per year may be higher. Also, the costs do not include administrative costs related to the application.

With a higher share of restrictions in applications related to category 1-3 nature, the costs would be higher. At present, it is assumed that less than 10 per cent of new livestock expansions are located on farms near category 1 nature sites.

The interval of 4-9 million DKK/year for livestock farms actual expanding near nature sites (category 1-3) is very uncertain and is only provided to give a rough estimate. This figure could be compared to the total production cost, and the costs can be a large burden for the farms in question. The analyses have not looked at the costs for existing farms, which might be given new emission limits when they carry out larger reinvestments.

To provide a more precise estimate of the costs, a better overview of the current applications needs to be provided so that the requirements can be linked to the different nature categories. Requirements might vary especially with respect to category 3 nature where local assessments are made. Furthermore, the analysis could include more case farms and more sizes based on the actual applications made.

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Appendices

Appendix A. An overview of the rules from before 1 August 2017

Rules until1 August 2017			
When permitting livestock installations	**§ 10 Farms of 15-75 AU (Fur farms of 3-25 AU)**	**§ 11 Farms of 75-250 AU (Fur farms 25-250 AU)**	**§ 12 Farms of more than 250 AU**
Technology / emission limits	BAT	BAT *and* 30 % emission reduction compared to 2005/2006 level	BAT *and* 30 % emission reduction compared to 2005/2006 level
Maximum deposition on category 1 habitats	No maximum	0.2-0.7 kg N/ha/year depending on number of farms in proximity	0.2-0.7 kg N/ha/year depending on number of farms in proximity
Maximum deposition on category 2 habitats	No maximum	1.0 kg N/ha/year	1.0 kg N/ha/year
Maximum deposition on category 3 habitats	No maximum	Individual assessment above 1.0 kg N/ha/year	Individual assessment above 1.0 kg N/ha/year
Maximum deposition on other nutrient sensitive habitats, e.g. ponds and meadows	Individual assessment	Individual assessment	Individual assessment
Impact on Annex IV species and habitats	Individual assessment	Individual assessment	Individual assessment

Neighbour effect:

- Number of livestock farms over 15 AU within 200 meter
- + Number of livestock farms over 45 AU within 200-300 meter
- + Number of livestock farms over 75 AU within 300-500 meter
- + Number of livestock farms over 150 AU within 500-1000 meter
- + Number of livestock farms over 500 AU, which affects with more than 0.3 kg N/ha over 1000 meters.

Note: The BAT emission requirements vary with farm size.

Appendix B. An overview of the rules from 1 August 2017

Rules from 1 August 2017		
When permitting livestock installations	**Above 100 m^2 production area**	**IED-thresholds or above 3.500 kg NH_3-N/year**
Technology / emission limits	BAT if emission exceeds 750 kg NH_3-N/year	BAT
Maximum deposition on category 1 habitats	0.2-0.7 kg N/ha/year depending on number of farms in proximity	0.2-0.7 kg N/ha/year depending on number of farms in proximity
Maximum deposition on category 2 habitats	1.0 kg N/ha/year	1.0 kg N/ha/year
Maximum deposition on category 3 habitats	Individual assessment above 1.0 kg N/ha/year	Individual assessment above 1.0 kg N/ha/year
Maximum deposition on other sensitive habitats, e.g. ponds and meadows	Individual assessment	Individual assessment
Impact on Annex IV species and habitats	Individual assessment	Individual assessment

Appendix C. The estimated use of new technologies related to ammonia emission (per cent of production)

Production	Environmental technology	2015	2020	2025	2030
Sows	Cooling	12	20	30	41
	Biological air washer	3	6	8	11
	Acidification	1	1	2	3
	Chemical air washer	1	1	1	2
Finishers	Cooling	1	5	9	13
	Biological air washer	< 1	2	3	5
	Acidification	1	2	4	5
	Chemical air washer	< 1	1	3	4
Piglets	Cooling	2	8	13	19
	Biological air washer	1	3	5	7
	Acidification	1	3	5	7
	Chemical air washer	< 1	0	0	1
Dairy cows	Acidification	5	7	10	12

Source: Mikkelsen and Albrektsen (2017)

Appendix D. Conversion from animal units to size of building area in new regulation (m^2)

Animal	250 AU	750 AU
Dairy cows	1,650	4,950
Finishers	1,250	4,464
Piglets	2,606	7,819
Sows (farestier)	3,926	11,779
Sows (drægtighedstier)	2,708	8,124

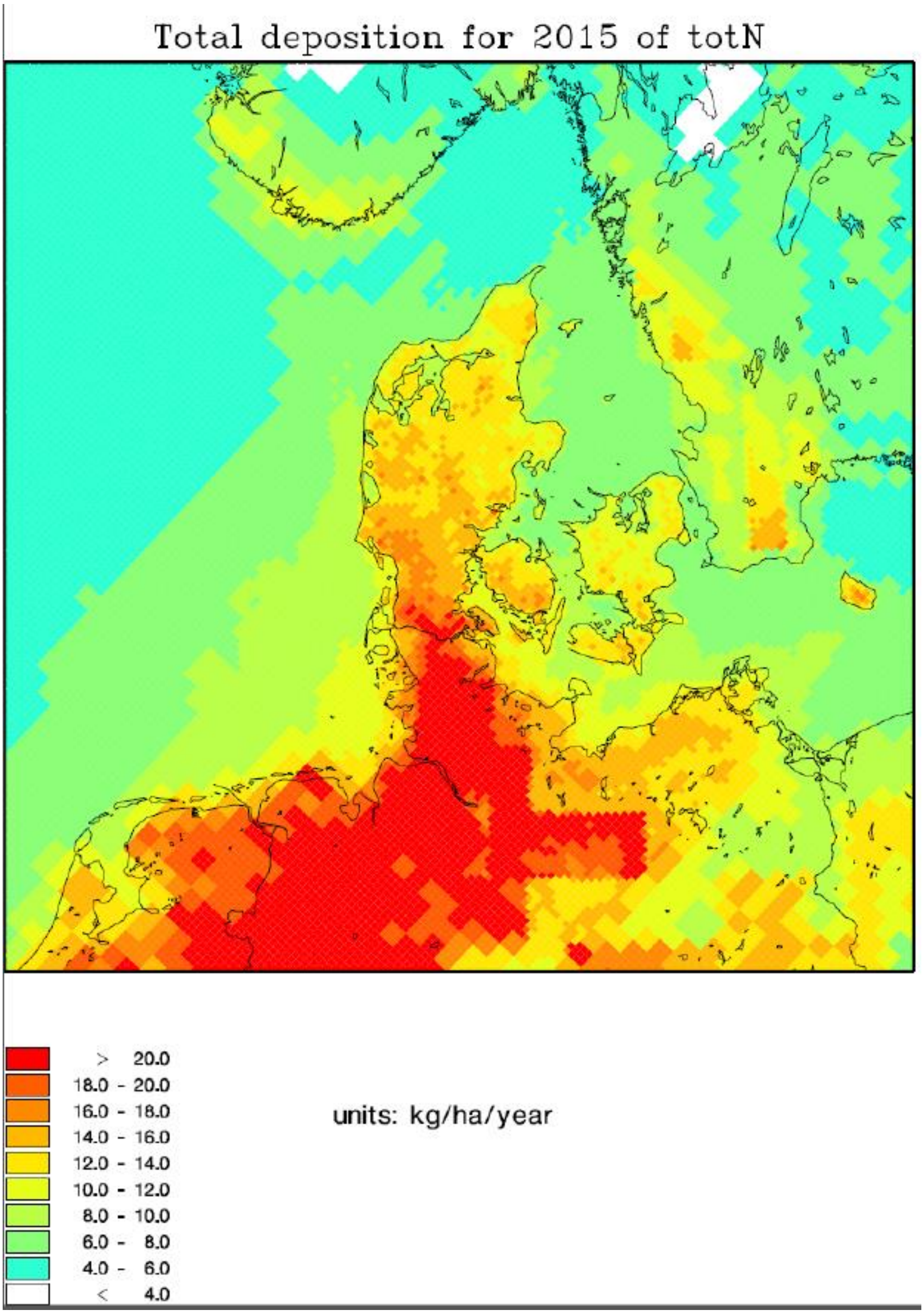
Note: For finishers, the conversion is 5 m^2 per AU (250 DE) and so 100 m^2 can hold around 20 AU (or produce 780 finishers per year).
Source: Kai and Adamsen (2017)

Appendix E. Reference technology and general emission requirements (GAK) in stables

	Reference technology	Kg N from animal	Kg NH_3-N loss (stables)	GAK Max emission per animal 2015/16	GAK Max emission per m^2	Reduction in stable (%)
Finishers (30-102 kg)	Partly slatted floor ((25-49 %).	3.08	0.40	0.32	1.6	16
Dairy cows without heifers	Cubicles with slatted flooring and scrapers	136.9	10.01	7.01-8.51*	0.7-0.85*	15-30*
Boilers (*1.000)	A loose housing system. *) 35 Days	48.7	6.52	6.3	0.57	24
Hens (*100)	Free range (indoor) with manure container	86.63	33.2	23.24	1.60	30
Sows 1	Gestation pens	18.49	2.51	1.76	0.87	29
Sows 2	Farrowing section	7.92	0.9	0.63	0.47	29

GAK = general ammonia emission requirement for extensions and renovated stables.
* Depending on the amount of grass in the total feed.
Source: Kai and Adamsen (2017, pp. 69,70)

Appendix F. N deposition (dry and wet) in Denmark in 2015



Source: Levin and Nygaard (2017).
Map showing N deposition:
http://envs.au.dk/videnudveksling/luft/model/deposition/danmark/nedfaldskort/